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WSEG REPORT 253

# OPERATIONAL TEST AND EVALUATION OF TACTICAL RADAR BOMBING SYSTEMS

## Results of Demonstration Test of a Bomb Scoring System

November 1974

*Including*
IDA Study S-444

C. H. Leatherbury, *Project Leader*
C. D. Manring, Capt. USN, *Project Officer*



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6 December 1974

MEMORANDUM FOR THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Results of the Demonstration Test of a Bomb Scoring System

1. This report is responsive to that portion of the Memorandum for WSEG from the Deputy Director (Test and Evaluation) requesting review and analysis of the demonstration tests of a bomb scoring system (WSEG Report 211). It also responds to an informal request from DD/T&E to investigate possible follow-on applications of the RABVAL instrumentation, originally planned for the final report.

2. The study concludes that the Bomb Scoring System is suitable and sufficiently accurate for use in the operational test and evaluation of A-6E and F-111F tactical radar bombing systems. The system meets the accuracy scoring goal of a radial error less than 20 feet under most conditions; scoring accuracy degrades somewhat at high speeds and very low altitudes. The demonstrated accuracy and operational characteristics of the system under various circumstances are delineated and discussed.

3. Based solely on experience gained in the demonstration test, the study identifies potential follow-on applications for the system. It appears feasible to extend the use of the bomb scoring system to include scoring of visually dropped bombs, range instrumentation and certain applications in tactical warfare.

M. H. Sappington

M. H. SAPPINGTON
Rear Admiral, USN
Acting Director

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STUDY S-444

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## Results of Demonstration Test of a Bomb Scoring System

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November 1974

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order DAHC-15-73-C-0200-T-179, dated 24 April 1973.

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## GLOSSARY

| | |
|---|---|
| ADTC | Armament Development and Test Center |
| AFATL | Air Force Armament Test Laboratory |
| AGL | above ground level |
| ARIS | Airborne Range Instrumentation System |
| BIT | built-in test |
| BSS | Bomb Scoring System |
| CAINS | Carrier Aircraft Inertial Navigation System |
| CEP | circular error probable |
| CLASS | Close Air Support System |
| Hg | mercury |
| IMU | inertial measurement unit |
| INS | inertial navigation system |
| IRIG | Inter-Range Instrumentation Group |
| MALT | Mobile Automatic Laser Tracking System |
| MCU | manual control unit |
| MTBF | mean time between failure |
| nmi | nautical mile |
| ODDR&E | Office of the Director of Defense Research and Engineering |
| OT&E | operational test and evaluation |
| RAT | ram air turbine |
| RBS | radar bomb scoring |
| RMS | root mean square |
| TDY | temporary duty |

# PREFACE

In February 1973, the Director of Defense Research and Engineering procured from Litton Guidance and Control Systems a Bomb Scoring System (BSS) for use in planned operational tests of F-111 and A-6 tactical aircraft radar bombing systems (Project RABVAL). The first of three procured systems was delivered to Eglin Air Force Base, Florida, in December 1973 for contractor and demonstration testing. The BSS was tested by the contractor from 15 December 1973 to 15 April 1974. Demonstration tests of the three systems were conducted from 15 April to 12 July 1974 in accordance with a test plan (Ref. 1) based on a test design (Ref. 2).

This study was prepared by C. H. Leatherbury and R. D. Mathews, Systems Evaluation Division, Institute for Defense Analyses (IDA), and by Colonel J. G. Bachman, USAF, and Captain C. D. Manring, USN, Weapons Systems Evaluation Group, DoD, in response to a request by the Director of Defense Research and Engineering (Ref. 3). IDA research effort on this study was requested by Weapons Systems Evaluation Group Task Order DAHC-15-73-C-0200-T-179 dated 24 April 1973.

# Part 1

# Introduction

# Introduction

This report presents the results of the demonstration tests of the Bomb Scoring System (BSS) developed by Litton Guidance and Control Systems.[1] In the past, tactical radar bombing accuracy tests by the Services have generally been conducted on controlled bombing ranges using readily identifiable radar reflective targets and, to a lesser extent, on USAF Strategic Air Command radar bomb scoring (RBS) sites against more realistic combat-like targets. Radar bombing accuracy against reflector targets is determined by measuring the impact location of inert bombs relative to the target; bombing accuracy on the RBS sites is determined from computations utilizing radar tracking and aircraft data during a simulated bomb run. Although radar bombing tests against reflector targets provide a measure of accuracy, the target is highly unrealistic compared to combat conditions. While RBS sites provide more realistic targets, the accuracy of the RBS system is not good enough to evaluate tactical bombing systems.

When the Deputy Director Test and Evaluation, ODDR&E, decided to conduct operational tests of A-6 and F-111 tactical radar bombing systems under simulated combat conditions, WSEG was requested (Ref. 4) to recommend appropriate instrumentation to accurately predict the impact of simulated bomb drops. An IDA recommendation that the Close Air Support System (CLASS) (Ref. 5) be adapted to bomb scoring led to the development of the BSS.

The BSS consists of a pod carried by tactical aircraft on a bomb station, an array of transponders on the ground at surveyed positions relative to the target, and associated ground support equipment. The pod contains an inertial navigation system, a distance measuring interrogator, an air data system, a data recording system, and associated power supply and cooling systems. (A pictorial description of the BSS is shown in Figure 4 *(page 16)*.)

To operate the system for bomb scoring, the BSS pod is mounted on an aircraft bomb pylon, necessary target coordinate and bomb ballistic inputs to the pod are inserted by magnetic tape cartridge, and the inertial system is aligned. When an aircraft on a bombing mission comes within 10 nmi of the ground transponders, the interrogator begins measurement of slant ranges and range rates to the various transponders and continues until the aircraft passes the target area. Range and range rate measurements are utilized with

1. Litton refers to this system as Airborne Range Instrumentation System (ARIS) to denote possible other uses in addition to bomb scoring.

inertial system outputs in a Kalman filter in an optimum manner to compute accurately release point position and velocity of the aircraft relative to the target or aimpoint. This information is used, with air data measurements and stored ballistic data, to compute the predicted impact of a bomb.

Demonstration tests of the BSS were conducted under controlled conditions at Eglin Air Force Base. A detailed description of these tests is presented in Chapter 1 of Part 3. The ability of the system to measure release point position and velocity was compared with precision ground instrumentation, including cinetheodolites, a laser tracker, and ballistic cameras. The performance of the system was also checked by comparing predicted bomb impacts with actual impacts.

Preliminary examination of results of the demonstration tests led to a decision that the system was capable of bomb scoring of F-111F and A-6E operational tests. (A discussion of the application of the system to other tests, and system limitations, is included in Part 2.) On 10 July 1974, the three Bomb Scoring Systems and associated equipment were shipped to Mountain Home Air Force Base, Idaho, for F-111F tactical radar bombing operational tests that commenced on 29 July 1974. The system will be used for the F-111 tests for approximately 3½ months in the Western United States, followed by 3½ months of operational tests in the East with the A-6E aircraft based at Oceana Naval Air Station, Virginia.

The following Part 2, Discussion and Summary, contains specific references to the detailed analyses of Part 3, which are developed in three chapters. Chapter I provides a description of the BSS test instrumentation employed at Eglin Air Force Base during the demonstration tests, and a description of test operations. Chapter II presents the accuracy results of the BSS as derived from simulated bomb drop tests, actual bomb drop tests, and self-survey tests. Chapter III is concerned with the operational suitability of the BSS. It includes a discussion of the reliability, maintainability, and other operational suitability factors. It also discusses possible uses of the BSS after completion of operational tests of F-111 and A-6 tactical aircraft bombing systems.

# Part 2

# Discussion and Summary

# Discussion and Summary

## A. GENERAL TEST DESCRIPTION

The purpose of the demonstration tests of the Bomb Scoring System (BSS) was to determine accuracy, reliability, maintainability, and operational suitability of the system. These tests were a prerequisite to the use of the BSS for scoring operational tests of A-6 and F-111 tactical radar bombing systems, and determining the application of the system to tasks other than bomb scoring. The demonstration tests were conducted at Eglin Air Force Base from 15 April to 12 July 1974.

The BSS was designed (Ref. 6) to score[1] simulated bomb drops for a variety of release conditions (aircraft altitudes of approximately 200 feet to 5,000 feet; aircraft speeds of 400 to 600 knots) to an accuracy of 20 feet root mean square (RMS) radial error, $\sigma_r$, in the target plane (CEP is approximately 16 feet)[2], neglecting release errors and ballistic uncertainties of the bombs. In order to achieve this scoring accuracy, the BSS accurately measures the position and velocity of an aircraft at the bomb release point relative to the target.

The CEP of an aircraft bombing system, including the effects of aircraft crew and bombs, may be determined from:

$$CEP_{System} = \sqrt{CEP_{UC}^2 - CEP_{BSS}^2 + CEP_{BD}^2} \cdot$$

where $CEP_{UC}$ = BSS score uncorrected for BSS errors and bomb dispersion.

$CEP_{BSS}$ = CEP of BSS for the profiles flown and type of bomb used.

$CEP_{BD}$ = CEP of ballistic dispersion for bombs assumed dropped.

The $CEP_{BSS}$ was accurately determined by external instrumentation during the demonstration tests for the *profiles flown and bomb types dropped.* These conditions included those to be used during OT&E tests and $CEP_{BSS}$ was found to be generally less than 20 feet.

The BSS cannot of course predict what the ballistic dispersion of a bomb will be due to physical anomolies, aerodynamic effects, etc. (In the BSS solution, aerodynamic effects and other separation effects are modeled and a nominal ballistic path calculated using wind

1. Predict impact point of an actual bomb had it been dropped from the simulated release point under the same position, velocity, wind, and density conditions.

2. For an assumed 2:1 (major-to-minor axis) elliptical distribution, CEP is approximately equal to 0.78 $\sigma_r$.

and density for the conditions at the aircraft.) $CEP_{BD}$ should be determined from a large number of drops of the bomb of interest under varying atmospheric conditions. During the demonstration tests, Mk 84 and Mk 82 (retarded) bombs were dropped to check the BSS ballistic program. For this particular batch of bombs, for the conditions tested, the $CEP_{BD}$ was less than 20 feet for the Mk 84 and less than 50 feet for the Mk 82 (retarded). This dispersion may vary considerably from these values for other conditions (i.e., high altitude drops with several unknown wind shears between drop altitude and the ground) and other types or batches of bombs. In summary, it is not expected that either $CEP_{BSS}$ or $CEP_{BD}$ will have any serious effect on determining $CEP_{System}$ in F-111F and A-6E OT&E tests since this value is expected to be more than twice the value of $CEP_{BSS}$ and $CEP_{BD}$ for the conditions to be tested. (Appendix B presents a numerical example and a detailed explanation.)

For tests utilizing the BSS that include flight profiles (altitudes and speeds) and bombs other than those checked during the demonstration tests, $CEP_{BSS}$ and $CEP_{BD}$ should be determined for the conditions of interest.

Several different types of tests were used to check the design performance of the BSS. The primary test of performance was to compare BSS measurements of velocity and position at the release point relative to that measured by precision ground-based instrumentation systems. The accuracy of the BSS relative to the 20-foot RMS scoring goal and accuracy variations with changes in BSS configuration and flight profiles were determined by calculations utilizing bomb ballistic sensitivities to release point errors.

The overall capability of the bomb scoring system to calculate bomb impact points—utilizing position, velocity, density, and wind vector measurements, and stored bomb ballistics—was determined (within the limits of bomb separation and ballistic uncertainties) by comparing actual bomb impact points with those predicted by the BSS *(Chapter II)*.

In addition to the bomb scoring capability, the BSS has a self-survey mode where the geographic position of ground transponders, relative to a known position, may be determined by repeated overflights. Performance in the survey mode was checked by comparison of BSS measurements with those of precise ground surveys.

The reliability, maintainability, and overall operational suitability of the BSS were qualitatively assessed by observation of system and support crew performance during the demonstration tests.

## B. TEST OPERATIONS

The demonstration tests of the BSS were conducted on ranges at Eglin Air Force Base with F-111E and A-6E aircraft. With the BSS installed on a wing pylon, test aircraft flew repeated simulated target runs over the transponder/target array on each sortie and were tracked by ground-based instrumentation systems located as shown in Figure 1. Actual bomb drops were accomplished generally at the beginning or the end of a series of simulated bomb runs. A total of 358 simulated runs, 38 actual bomb drops, and 7 survey mode tests were conducted, requiring a total of 72 aircraft sorties.

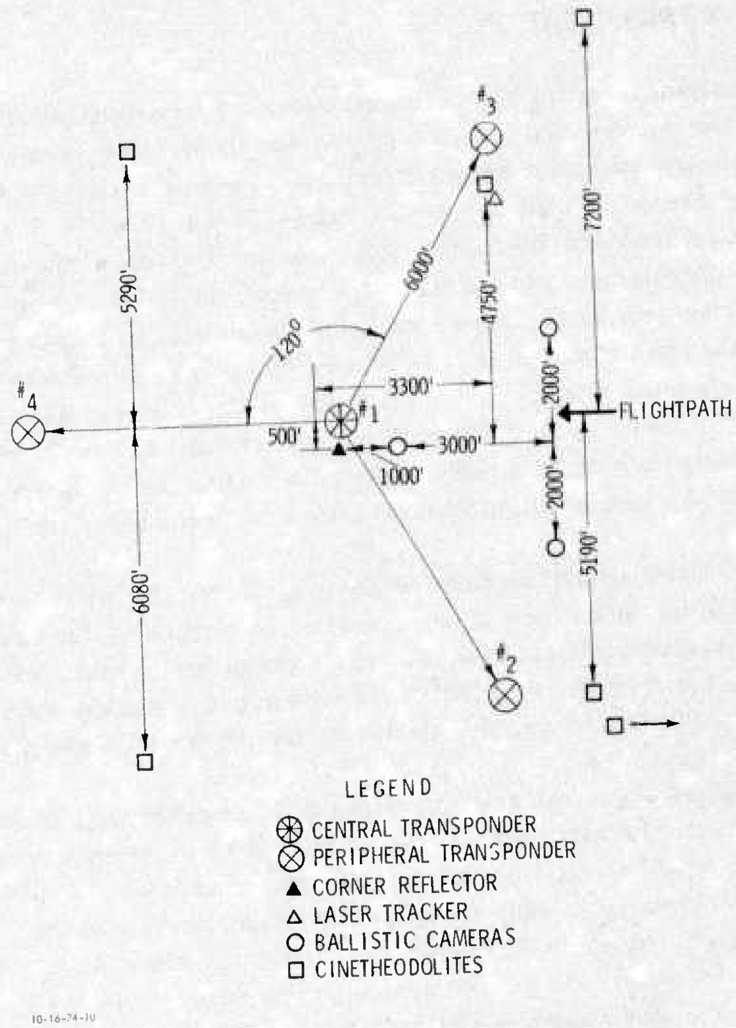


*Figure 1. Test Instrumentation Locations, B-70 Range, Eglin Air Force Base*

Test variables exercised during the demonstration tests included high- and low-drag bomb release profiles; different aircraft speeds, altitudes, and attitudes; various offsets of the aircraft flightpath relative to the central transponders; different aircraft maneuvers (climb, pullup, breakaway); and alternate numbers of transponders (two, three, four). Inert Mk 84 2,000-pound, low-drag and Mk 82 500-pound, high-drag (SNAKEYE) bombs were used for the actual bomb drop tests.

## C. TEST INSTRUMENTATION

Cinetheodolite, laser tracker, and ballistic camera instrumentation systems were used to measure the position and velocity of the aircraft at bomb release. Cinetheodolite instrumentation was used on essentially all runs, the laser tracker on about half of the runs, and ballistic cameras were used on a limited number of runs (19). The A-6 aircraft air data system was used to check BSS wind vector measurements on a few runs. Eglin AFB meteorological data were used to check BSS temperature and pressure measurements.

A common coordinate system was used for all ground instrumentation systems regardless of the actual point on the aircraft used for tracking. All instrumentation systems determined the position and velocity of the center of gravity of the BSS inertial measurement unit (IMU) relative to the location of the central transponder on the ground. Since all of the instrumentation systems actually tracked other points on the aircraft and pod, data reduction involved a transformation from the point actually tracked to the center of gravity of the IMU.

Contraves cinetheodolite locations on the range were such that at least four theodolites could track the aircraft on a target run in the vicinity of the release point. All cinetheodolites tracked the nose of the test aircraft, except for the runs made at night when a running light was tracked. In addition to determining the position and velocity of the release point, cinetheodolites provided track data for the aircraft flightpath prior to and after the release point.

A McDonnell-Douglas laser tracker was also used to measure the position and velocity at the release point. The laser tracker tracked a small array of retroreflectors mounted on the bottom of the BSS pod. The laser tracker was located on the B-70 range[3] and, therefore, did not provide data when target runs were made on other ranges.

Only 19 tests were run with ballistic camera instrumentation (1) to determine more accurately the BSS velocity and position accuracy at the release point, and (2) to check the performance of the cinetheodolites and laser tracker. Ballistic camera tracking and data reduction were accomplished by DBA Systems, Inc. The ballistic cameras tracked a precision strobe light mounted near the aft end of the BSS pod. All tests were conducted on clear nights to enable the ballistic camera to view a star background. As expected, the ballistic camera results permitted a very precise assessment of the performance of the BSS, laser tracker, and cinetheodolites under conditions tested.

Table 1 presents a summary of the accuracy of instrumentation relative to the ballistic camera. The BSS data are included to permit consideration of this system as a potential airborne range instrumentation system. A more detailed comparison of instrumentation accuracies is included in Chapter I of Part 3. The spherical probable error of the ballistic camera instrumentation at the bomb release point for these tests was 0.07 foot in

3. Two other ranges were used for a limited number of tests.

*Table 1. Accuracy of Test Instrumentation*
*(Difference Between Release Point Data of Cinetheodolites/Laser Tracker/ BSS and Ballistic Camera)*

| System | RMS Error for 19 Runs | | | | | |
|---|---|---|---|---|---|---|
| | Position (ft) | | | Velocity (ft/sec) | | |
| | Downrange | Crossrange | Altitude | Downrange | Crossrange | Vertical |
| Cinetheodolites | .5 | .9 | 2.3 | .32 | .23 | .55 |
| Laser Tracker | .3 | .5 | .6 | .38 | .35 | .24 |
| Bomb Scoring System | 1.9 | 2.7 | 4.1 | .16 | .27 | 1.03 |

Source: Table 7 *(page 25)*.

position and 0.03 foot per second in velocity for the geometric arrangement of Figure 1 and the 1,500-foot altitude used. The accuracy of the cinetheodolites and laser tracker was sufficient to check the performance of the BSS for bomb scoring; a better check of accuracy at the release point was provided by ballistic camera measurements.

## D. ACCURACY RESULTS

Accuracy results for the BSS, as determined by external instrumentation systems, are presented for simulated bomb drop tests, actual bomb drop tests, and self-survey mode tests.

Simulated bomb drop test results are shown in Tables 2 and 3. Table 2 presents the position and velocity accuracy of the BSS at the bomb release point as a function of the various test variables.

Table 3 shows the scoring accuracy of the BSS in the target plane in terms of RMS radial error, $\sigma_r$, calculated by multiplying the release point position and velocity errors by the ballistic sensitivity to those errors. In general, the BSS performed as expected from contractor design simulation results except for the very low altitude (200 feet) or high speed (550-600 knots) runs. Under these conditions, the BSS scoring error is considerably larger than the 20-foot radial error goal.[4] Whether the available accuracy under these conditions is satisfactory or not will depend on the weapon system being tested and the objective of the test.

4. The effect of BSS scoring error on determination of the CEP of an aircraft bombing system is presented in Appendix B.

*Table 2. Accuracies of Release Point Position and Velocity*

| Flight Profile Conditions | | | | | | Position (ft) | | | Velocity (ft/sec) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Altitude (ft AGL) | Speed (kt) | Offset* (ft) | No. of Trans-ponders | Maneuver | No. of Passes | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical |
| **High-Drag Simulated Bomb Drops** | | | | | | | | | | | |
| 200 | 400 | 500 | 4 | Level | 15 | 2.0 | 8.5 | 25.0 | .42 | .93 | .81 |
| 200 | 400 | 0 | 4 | Level | 22 | [illegible] | 10.9 | 5.1 | .55 | .85 | .83 |
| 200 | 400 | 1,000 | 4 | Level | 14 | 4.7 | 5.5 | 24.0 | .30 | .69 | 1.28 |
| 200 | 400 | 1,000 | 4 | Pullup† | 6 | 1.6 | 1.6 | 19.4 | .32 | .66 | 1.98 |
| 200 | 600 | 500 | 4 | Level | 8 | 7.1 | .1 | 12.2 | .30 | .98 | .76 |
| 500 | 400 | 500 | 4 | Level | 17 | 3.5 | 11.0 | 7.7 | .32 | .45 | 1.02 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 1.6 | 4.1 | 3.9 | .41 | .52 | .86 |
| 500** | 480/525 | 500 | 2 | Level | 15 | 1.1 | 6.9 | 6.6 | .20 | .52 | .70 |
| 500** | 480/525 | 500 | 3 | Level | 23 | 1.2 | 4.7 | 5.4 | .35 | .50 | 1.03 |
| **Low-Drag Simulated Bomb Drops** | | | | | | | | | | | |
| 500 | 400 | 500 | 4 | Level | 36 | 1.7 | 4.2 | 4.9 | .30 | .52 | .92 |
| 500 | 600 | 500 | 4 | Level | 18 | 3.2 | 8.6 | 9.6 | .45 | .98 | 1.73 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 2.4 | 4.6 | 8.6 | .35 | .35 | 1.05 |
| 5,000 | 400 | 500 | 4 | Level | 22 | 4.1 | 9.9 | 12.4 | .31 | .39 | .79 |
| 5,000 | 500 | 500 | 4 | Level | 10 | 7.8 | 8.3 | 23.0 | .65 | .40 | 1.84 |
| 10,000 | 400 | 500 | 4 | Level | 21 | 11.3 | 8.3 | 16.8 | .48 | .31 | .92 |
| 500 | 400 | 500 | 4 | 10 deg climb | 12 | 2.2 | 10.3 | 4.9 | .81 | .92 | .94 |
| 500 | 400 | 500 | 4 | Pullup† | 8 | 1.7 | 3.6 | 6.2 | .22 | .70 | .95 |
| 500 | 550 | 500 | 4 | Pullup† | 12 | 1.7 | 3.8 | 4.8 | .43 | .52 | 1.03 |
| 500 | 400 | 0 | 4 | Breakaway† | 20 | 1.9 | 4.6 | 3.9 | .31 | .57 | .85 |
| 1,000** | 420/480 | 500 | 2 | Level | 14 | 2.0 | 9.2 | 6.3 | .43 | .26 | .82 |
| 1,000** | 420/480 | 500 | 3 | Level | 26 | 1.4 | 3.5 | 3.9 | .35 | .58 | .92 |

*From center transponder.

†After simulated release.

**Profiles in operational tests of A-6E and F-111F.

The BSS has the capability of estimating achieved scoring accuracy. This scoring error estimate may be used to determine BSS performance for a particular aircraft bombing run. (A detailed discussion of the BSS self-error estimating capability is presented in Chapter II of Part 3.)

Results of bomb drop tests are presented in Figures 2 and 3. BSS predicted impacts are compared with actual impacts of Mk 84 2,000-pound, low-drag and Mk 82 500-pound, high-drag bombs. These results reflect the overall performance of the BSS utilizing position

*Table 3. Accuracy of BSS Scoring*

| Flight Profile Conditions | | | | | No. of Passes | Ground Impact Scoring Accuracy (RMS Radial Error, $\sigma_r$) (ft) |
|---|---|---|---|---|---|---|
| Altitude (ft AGL) | Speed (kt) | Offset* (ft) | No. of Transponders | Maneuver | | |
| **High-Drag Simulated Bomb Drops** | | | | | | |
| 200 | 400 | 500 | 4 | Level | 15 | 101.7 |
| 200 | 400 | 0 | 4 | Level | 22 | 15.7 |
| 200 | 400 | 1,000 | 4 | Level | 14 | 73.0 |
| 200 | 400 | 1,000 | 4 | Pullup† | 6 | 44.3 |
| 200 | 600 | 500 | 4 | Level | 8 | 51.1 |
| 500 | 400 | 500 | 4 | Level | 17 | 16.8 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 9.7 |
| 500** | 480/525 | 500 | 2 | Level | 15 | 14.0 |
| 500** | 480/525 | 500 | 3 | Level | 23 | 11.9 |
| **Low-Drag Simulated Bomb Drops** | | | | | | |
| 500 | 400 | 500 | 4 | Level | 36 | 15.3 |
| 500 | 600 | 500 | 4 | Level | 18 | 42.8 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 18.6 |
| 5,000 | 400 | 500 | 4 | Level | 22 | 14.2 |
| 5,000 | 500 | 500 | 4 | Level | 10 | 18.6 |
| 10,000 | 400 | 500 | 4 | Level | 21 | 3.2 |
| 500 | 400 | 500 | 4 | 10 deg climb | 12 | 23.1 |
| 500 | 400 | 500 | 4 | Pullup† | 8 | 11.6 |
| 500 | 550 | 500 | 4 | Pullup† | 12 | 32.8 |
| 500 | 400 | 0 | 4 | Breakaway† | 20 | 17.3 |
| 1,000** | 420/480 | 500 | 2 | Level | 14 | 22.7 |
| 1,000** | 420/480 | 500 | 3 | Level | 26 | 17.5 |

*From center transponder.

†After simulated release.

**Profiles in operational tests of A-6E and F-111F.

Source: Table 17 *(page 40)*.

and velocity measurements, air data measurements, and ballistic programs. Although unknown bomb dispersion is included in these results, it is considered that these tests demonstrate the accuracy of prediction by the BSS to be generally satisfactory for tests of this type.

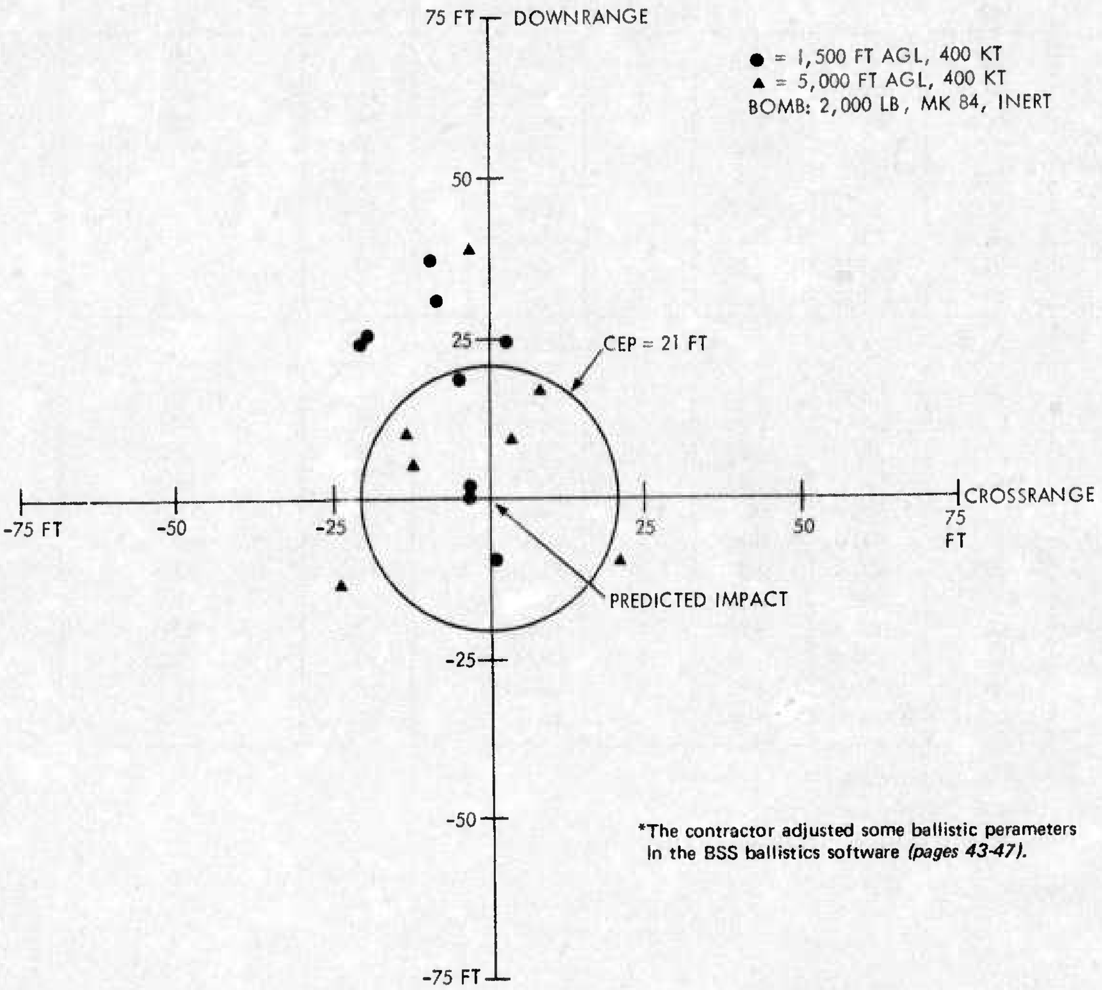


*Figure 2. Actual Impacts Relative to Predicted Impacts After Adjustment**
*(Low-Drag Bombs)*

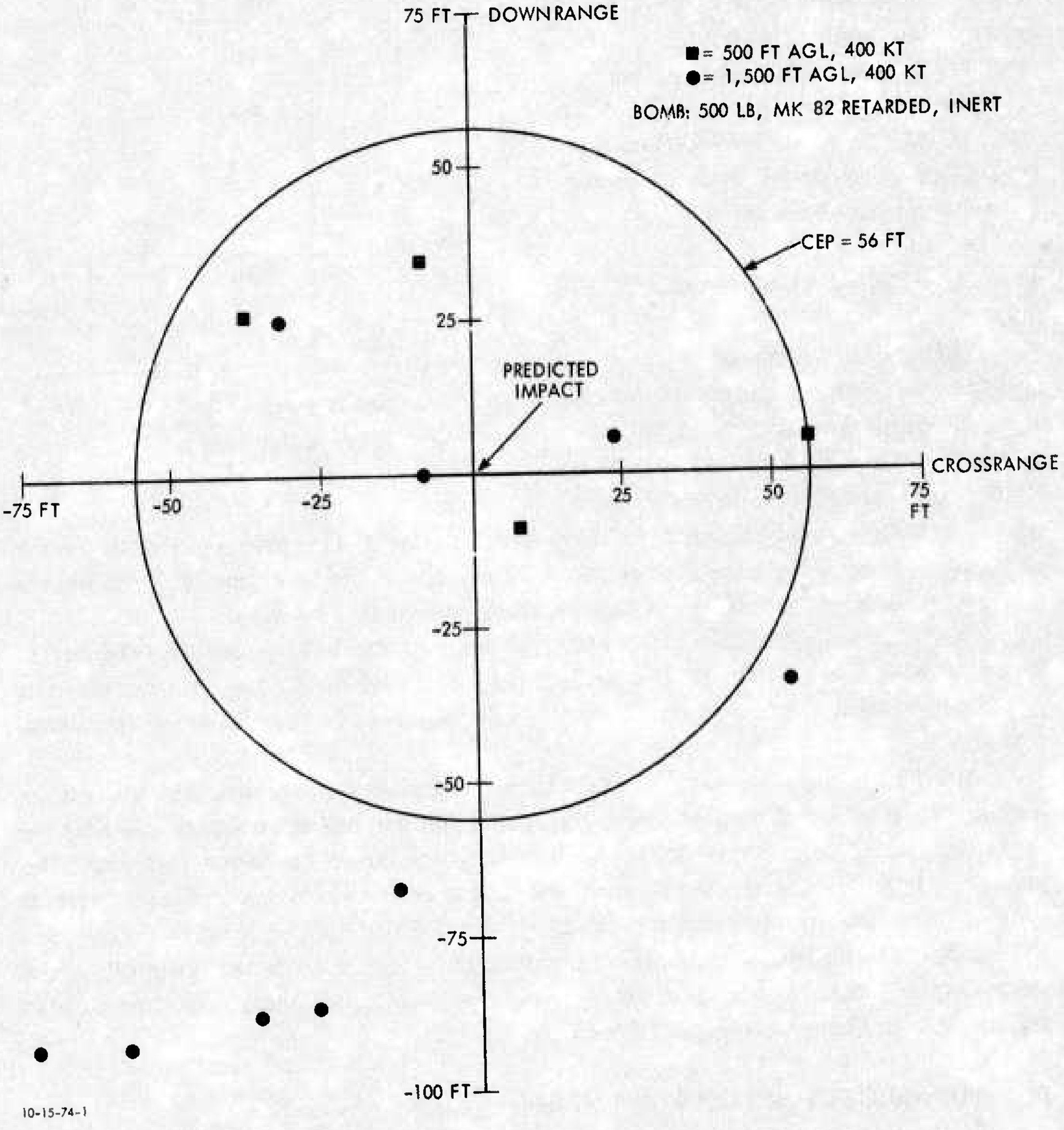


*Figure 3. Actual Impacts Relative to Predicted Impacts (High-Drag Bombs)*

Self-survey mode test results for the BSS are shown in Table 4. The demonstration test results were not as accurate as expected from simulations (2 feet horizontal plane and 5 feet vertical plane). While this indicated performance will not be particularly detrimental to transponder location for bomb scoring purposes, the indicated accuracy may not be suitable for other possible survey applications. It may be possible to improve performance of the survey mode by further development and testing of the software.

*Table 4. Test Results of Self-Survey Mode*

| Outer Transponder No. | BSS Surveyed Position of Outer Transponders Minus True Position (ft) | | |
|---|---|---|---|
| | East | North | Up |
| 1 | -1.1 | -2.4 | 3.5 |
| 2 | 1.7 | 3.7 | 5.2 |
| 3 | -6.8 | -.3 | 3.2 |
| 1 | -.6 | -4.9 | 9.0 |
| 2 | .1 | 6.4 | 1.5 |
| 3 | -2.5 | -.8 | -9.0 |
| 1 | -11.0 | 2.8 | 4.3 |
| 2 | 14.0 | 1.1 | 5.1 |
| 3 | -3.2 | -14.7 | 20.9 |
| RMS Error | 6.5 | 5.9 | 8.8 |

Source: Table 22 *(page 51)*.

## E. OPERATIONAL SUITABILITY

Operational suitability of the BSS, based on the limited experience derived from the demonstration tests, is discussed in detail in Chapter III of Part 3. Demonstration test experience indicates that one of three BSSs can be expected to be available during F-111 and A-6 aircraft testing essentially all the time, two of three about 90 percent of the time, and all three systems about 50 percent of the time—an average availability of about 80 percent.

Based upon approximately 165 operating hours of the BSS, an inflight reliability of about 70 percent was achieved. Discounting items corrected during the tests and counting partial successes, it appears that a 90 percent reliability may be possible during operational testing.

The BSS is specialized instrumentation requiring skilled engineering support, environmentally controlled maintenance space, and special test and support equipment. During the contractor and demonstration tests, the BSS was maintained by Litton personnel. This practice is being continued during operational testing of the F-111 and A-6 radar bombing systems. In view of the inherent complexity of the BSS and the requirement for considerable skilled maintenance, contractor maintenance (as opposed to Service maintenance) of the system in future operations should be considered. (Additional operational characteristics are discussed in Chapter III *(pages 67-68)*.)

## F. POSSIBLE FUTURE USES OF THE BSS

It has been demonstrated that the BSS can accurately score simulated bomb drops of high speed aircraft at low altitudes against realistic targets. Upon completion of utilization of the system for scoring F-111F and A-6E operational tests, several possibilities exist for future use. These possible uses, discussed further in Chapter III *(pages 68-72)* are summarized below:

(1) *Additional Radar and Visual Bomb Scoring Tests.* All current Joint Munitions Effectiveness Manual bombing data are largely based on aircraft/crew performance against unrealistic targets relative to combat conditions. It would be desirable to correct these data by use of the BSS on tests of all inventory and programmed combat aircraft with the capability of dropping gravity ordnance.

(2) *Training Aid.* The BSS can be used as a training aid during routine testing of aircraft/crews, allowing a variety of realistic target problems.

(3) *Range Instrumentation System.* The BSS may be used as an airborne instrumentation system, providing position, velocity, and air data information on the aircraft carrying the pod. Within speed and altitude restraints (Table 3), the advantages of the system as compared to conventional ground-based optical systems include all-weather performance, relative mobility, and near real time data.

(4) *Surveying System.* In the self-survey mode, the BSS may be used to survey the location of ground transponders relative to a known position. This may be particularly useful in areas of rough terrain.

(5) *Combat Systems.* Several possibilities exist for use of BSS technology for combat purposes:

(a) As an *all-weather bomb-nav system* for day fighter aircraft (pod-mounted) or for remotely piloted vehicles on close air support, interdiction, or reconnaissance missions.

(b) As an *all-weather airborne locator/control system* for air, ground, and sea units.

(c) As a *mobile instrument landing system,* particularly in advanced base areas.

None of the above possible uses of the BSS, other than bomb scoring, have been examined in depth in this study. However, the possibilities of BSS technology appear to warrant further investigation. If additional quantities of the BSS are procured, consideration should be given to reduction of the size and weight of the system. This reduction is technically feasible and would be particularly important for combat applications. Incorporation of another cooling system, in liew of the current dry ice system, would also be a worthwhile improvement.

## G. SUMMARY–DEMONSTRATION TEST OF BSS

1. The BSS can accurately score simulated gravity bomb drops under conditions of 400 to 500 knots speed, 500 to 10,000 feet altitude, 0 to 500 feet flightpath offset from

the center transponder, level or maneuvering flight, and during day, night, and IFR weather. Under these conditions, the RMS radial scoring error[5] of the BSS should not exceed 10 to 25 feet, neglecting bomb dispersion. Accuracy of the BSS degrades as indicated in Table 3 with high speed (550 to 600 knots) and with very low altitude (200 feet) bomb runs with large offsets.

2. On the basis of limited demonstration test experience, it appears that an availability of approximately 80 percent and an inflight reliability of about 90 percent can be expected for the BSS during operational testing. The system requires skilled maintenance personnel and special test and support equipment.

3. The demonstrated capability of the BSS presents the possibility of several future uses after completion of F-111F and A-6E operational tests, including:

(a) Additional operational testing of aircraft bombing accuracy

(b) Training aid

(c) Range instrumentation system

(d) Surveying system

(e) Combat systems: all weather bomb-nav, airborne locator/control, instrument landing.

These possible future uses of the system, and associated technology, should be investigated further.

5. For an assumed 2:1 (major-to-minor axis) elliptical distribution, CEP is approximately equal to $0.78\sigma_r$.

# Part 3

# Analyses

Chapter I

# DESCRIPTION OF THE DEMONSTRATION TEST OF THE BOMB SCORING SYSTEM

This chapter describes the demonstration testing of the Bomb Scoring System (BSS) produced by the Guidance and Control Division of Litton Industries.[1] The tests were conducted at Eglin Air Force Base, Florida, from 15 April to 12 July 1974.

## A. BOMB SCORING SYSTEM

The BSS is described in detail in the test design (Ref. 2), the contractor's Operating Manual (Ref. 7), and the Test Director's Report (Ref. 8). The system is designed to score simulated bomb releases under all weather conditions against a variety of realistic cultural targets with a scoring accuracy of 20 feet RMS radial error or less. It consists of a pod (approximately 800 pounds, 16 feet long, and 22 inches in diameter) and a ground array of suitcase-size transponders, each with a folding ground plane antenna. These are shown schematically in Figure 4. The system requires two ground support consoles, one for maintenance of the hardware and the other for processing data; plus ancillary test and support equipments.

The insert in Figure 4 shows the basic pod components, including its own inertial navigation system (INS),[2] power supplies, cooling system, interrogator, tape recorder, and air data system, all completely independent of any system in the test aircraft.[3] For test purposes only, pods were temporarily modified to provide Inter-Range Instrumentation Group (IRIG B) time correlation, reflectors for tracking by special laser instrumentation, and a strobe light on pod number three for ballistic cameras.

The transponders are placed around the desired target for bomb scoring, and precisely located with respect to the target and each other either by a ground survey or from the air by the BSS in its self-survey mode. Using the ground data terminal, a tape is prepared with

1. The acronym assigned to the system by Litton is ARIS (Airborne Range Instrumentation System).

2. The pod INS is comprised of the four basic units of the AN/ASN-92 CAINS: a control indicator unit, a power supply unit, an inertial measurement unit (IMU), and a computer unit. The computer has been modified with additional memory and software programming unique to the BSS.

3. A connecting umbilical from the aircraft pylon provides for a bomb release signal to the pod and for aircraft power to selectable pod units if desired.

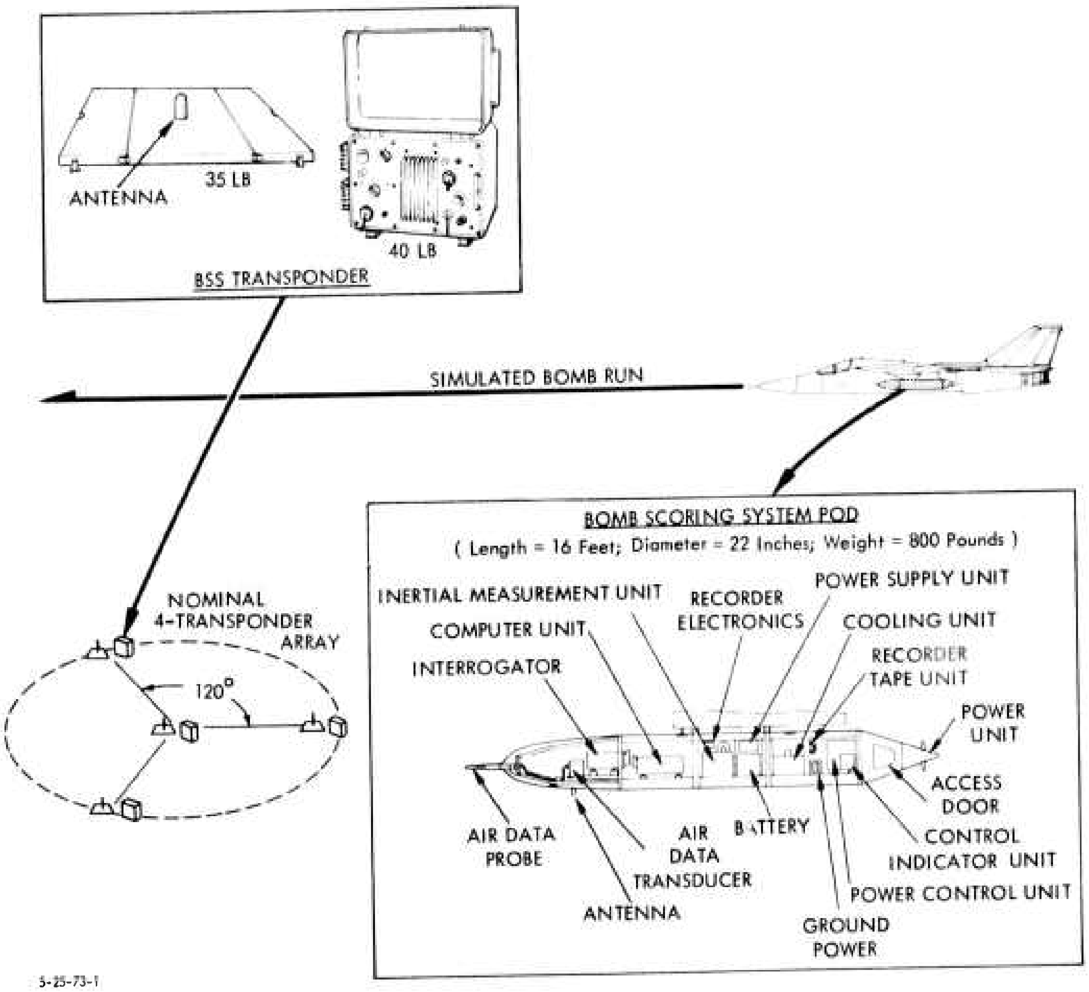


*Figure 4. Bomb Scoring System*

the survey data and other basic information for insertion into the pod computer memory.

As the aircraft flies to the target, the pod independently determines its own position with its internal INS. When it senses that it is within 10 miles of a target array, the pod commences interrogation of the ground transponders. By sequentially sampling ranges and range rates with respect to each transponder, a computer subprogram, known as a Kalman filter, rapidly converges on the pod's position in space with respect to the target.[4] When a bomb release signal is received from the aircraft, the pod continues smoothing its solution as it passes over the target array and for 2 miles beyond the center transponder. Then it computes the fall of a simulated bomb, using a ballistic program, and stores in computer memory and on tape the predicted downrange and crossrange miss errors, along with an estimate of pod prediction error based on the relative quality of position and velocity computations made by the Kalman filter. Upon return to base, the bomb impact prediction can be read out manually on the pod control panel or printed out on the data terminal.[5] Continuous navigation and update data, aircraft performance parameters, air data, and automatic system self-test results are also stored on tape throughout the flight, as described in Appendix A, and these can be printed out for comprehensive analysis of the total aircraft/BSS performance.

## B. CONDUCT OF THE DEMONSTRATION TEST

### 1. Organization and Schedule

Joint testing of the BSS was sponsored by the Deputy Director Test and Evaluation, ODDR&E. The Institute for Defense Analyses was tasked to provide a test design (Ref. 2) as part of its evaluation of tactical radar bombing systems (Project RABVAL). The Air Force was tasked to provide a Test Director and the Navy a Deputy Test Director; the test directorate produced a joint test plan (Ref. 1) based on the test design. Air Force F-111E aircraft and crews were provided by the 422nd Fighter Weapons Squadron operating from Nellis AFB, Nevada. Navy A-6E aircraft and crews were provided by the Air Test and Evaluation Squadron 5 detachment at NAS Oceana, Virginia.

A Joint site selection team determined that the Armament Development and Test Center (ADTC) at Eglin AFB was the most suitable test range to meet the overall operational and technical requirements of the RABVAL test program. A building located on the flight line at Eglin AFB was provided for the duration of the testing, adequately equipped with shop, administrative, and briefing facilities for the test directorate, flight crews, and contractors. ADTC provided test range facilities, ground surveys, tracking

4. The Kalman filter subprogram compares the measured values of range and range rate with the corresponding values computed from inertial inputs and utilizes the differences as error signals to update the computations of aircraft position, velocity, and attitude. Initially the Kalman filter employs an eight-state error model (three components each of aircraft position and attitude and two horizontal components of velocity). After release, the filter augments these eight present position states with five more release point states (three components of release point position and two horizontal components of release point velocity) and continues to use range and range rate measurements to improve on its computation of the release point position and velocity.

5. Provision for telemetering selected data down the radio link is also incorporated in the system design for readout at any of the transponders if desired.

instrumentation, IRIG B timing correlation, meteorological observations for the test runs, and data reduction services.

The pod was certified for both Navy and Air Force carriage in December 1973, and recertified for minor modifications as the demonstration testing progressed. Unexpected difficulty with the ram air turbine power supply caused slippage in the contractor's development phase, scheduled from 15 December 1973 to 15 April 1974. Rather than delay demonstration testing, it was decided to proceed on the original schedule but to permit the contractor to continue to make developmental changes, subject to the concurrence of the test directorate in each case. Nominally, the demonstration testing commenced 17 April and was completed 12 July 1974. No substantive change to the scoring software was permitted during the testing, since such changes might have affected accuracy at the release point and, in turn, impacted on the data base. There were improvements and refinements, however, on the program logic and mechanization, the ballistic subprogram, and the survey mode.

## 2. Demonstration Test Procedures

The demonstration testing of the BSS had two basic objectives: to determine the accuracy of the BSS in measuring position and velocity for bomb scoring under a variety of conditions, and to make a qualitative evaluation of the operational suitability of the BSS.

Table 5 lists the flight profiles planned, and compares the runs planned with the runs successfully tracked. The self-survey missions performed a repeated, simple descending spiral over the array. For bomb scoring missions, the profile was a repeated racetrack pattern over the instrumented range, with a 15-mile straight run-in to the target and a 5-mile overrun beyond the target, at the various altitudes, speeds, and offsets shown in the table. The aimpoint was a radar reflector. The target array was varied from one to four transponders to investigate the effect of array geometry on the scoring solution. The basic configuration of the transponders and range instrumentation is depicted in Figure 5.

As an empirical check on impact simulations, 48 inert bombs (24 2,000-pound low drag and 24 500-pound high drag) were provided for individual drops throughout the test series. Weight, moment, and center-of-gravity data were provided for each bomb, and individual drops were tracked for supplementary ballistic data. Actual impact points were measured to an accuracy of less than 1 foot for comparison with BSS impact predictions. (See Chapter II for the analysis.) Of the 48 bombs procured, 29 produced useful data, 12 did not produce useful data, and 7 were not dropped because of aircraft and scheduling problems.

Insofar as possible, the flights were evenly divided between the A-6 and F-111. During the demonstration phase, flights were initially planned to provide at least 70 passes per week, later increased to 80 passes per week to make up for scheduling delays. When time and circumstances permitted on a given sortie, extra passes were often made. On several occasions, profiles planned could not be flown because of range or weather restrictions and substitute profiles were flown instead. Not all profiles were flown exactly as prescribed, resulting in some minor adjustments to the data matrix.

*Table 5. Flight Summary of Demonstration Test*

| Flight Profile | Altitude (ft AGL) | Speed (kt) | Offset (ft) | Runs Planned | Runs Tracked* | | |
|---|---|---|---|---|---|---|---|
| | | | | | Cine-theodolite | Laser Tracker | Ballistic Camera |
| High-Drag Reference | 200 | 400 | 500 | 20 | 16 | 9 | |
| No Offset | 200 | 400 | 0 | 20 | 21 | 13 | |
| Large Offset | 200 | 400 | 1,000 | 20 | 14 | 6 | |
| High Speed | 200 | 600 | 500 | 28 | 12 | 4 | |
| Mid-Altitude | 500 | 400 | 500 | 36 | 18 | 10 | |
| High Altitude | 1,500 | 400 | 500 | 28 | 22 | 15 | 2 |
| Array Changes | 500 | 500 | 500 | 20 | 9 | 8 | |
| Operational | 500 | 500 | 500 | 24 | 22 | | |
| Breakaway | 200 | 400 | 0 | 0 | 1 | 1 | |
| Pullup | 200 | 400 | 1,000 | 0 | 6 | 3 | |
| Array Changes | 1,000 | 500 | 500 | 0 | 7 | 5 | |
| Low-Drag Reference | 500 | 400 | 500 | 58 | 33 | 16 | |
| High Speed | 500 | 600 | 500 | 28 | 20 | 2 | |
| Mid-Altitude | 1,500 | 400 | 500 | 28 | 35 | 21 | 11 |
| High Altitude | 5,000 | 400 | 500 | 20 | 22 | 10 | |
| Climb 10 Degrees | 500 | 400 | 500 | 20 | 15 | 12 | |
| Very High Altitude | 10,000 | 400 | 500 | 20 | 21 | 10 | |
| Pullup 30 Degrees | 500 | 400 | 500 | 20 | 20 | 12 | |
| Breakaway | 500 | 400 | 0 | 20 | 20 | 10 | |
| Array Changes | 1,000 | 400 | 500 | 20 | 17 | 14 | |
| Low Operational | 1,000 | 500 | 500 | 24 | 26 | 14 | |
| Extreme Altitude | 25,000 | 400 | 500 | 0 | 3 | 1 | |
| Ballistic Camera | 1,500 | 600 | 500 | 0 | 6 | 4 | 6 |
| Bomb Drops | 5,000 | 500 | 500 | 0 | 10 | 6 | |
| Total | | | | 454 | 396 | 206 | 19 |
| Self-Survey | Variable | 400 | N/A | 4 | | | |

*All runs tracked by the laser trecker or bellistic cameras were also tracked by cinethaodolites, so that total number of runs tracked was 396.

A standard briefing sheet was prepared for each sortie, and retained in the data package, as a common detailed reference for the range instrumentation teams, flight crews, loading personnel, and contractor representatives. Each flight crew filled out a kneeboard data card for the sortie data package showing actual results and flight parameters observed as the sortie progressed. Some radar scope photography at the release point was also obtained by the flight crews. All flights were kept under radar observation throughout the scoring portion of their sorties and advised throughout their flight patterns in an attempt to assure that the aircraft was within the required instrumentation window at release.

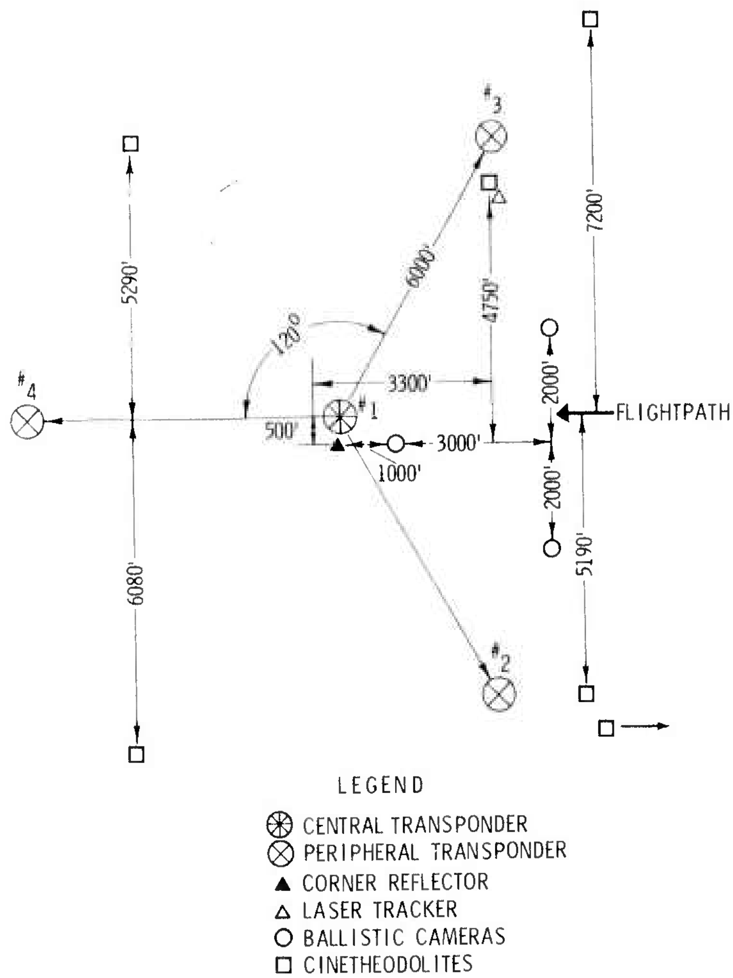


*Figure 5. Test Instrumentation Locations, B-70 Range, Eglin Air Force Base*

### 3. Data Handling

Data analysts from the 6585th Test Group at Holloman AFB, New Mexico, supervised test data collection. Individual sortie folders were prepared containing the sortie brief sheet, kneeboard data cards, radar plots, and radar scope photography when it was obtained. A release frame printout was supplied by Litton immediately after each flight.

Detailed data listings were subsequently produced by each of the instrumentation systems, and cross-referenced by sortie. A copy of the pod tape was normally available in less than 24 hours. Radar and cinetheodolite tracking data for each sortie were reduced by the ADTC Mathematics Laboratory at Eglin AFB.[6] AFATL provided the ballistic analysis for the actual bomb drops. A run-by-run compilation could be produced, normally in less than a week, listing all cinetheodolite flight tape data, plus differencing with respect to the corresponding BSS data. Data from the laser tracker were delivered in a run-by-run format for comparative analysis, usually within 5 days. Later in the test program, a laser tracker tape was supplied to the ADTC Mathematics Laboratory for differencing along with the cinetheodolite and BSS data. On those few sorties in which ballistic cameras were used, the camera plates were developed and examined immediately on site to verify that usable data had been recorded, then sent back to the DBA Systems, Inc., laboratory for detailed analysis. The initial report required about 6 weeks, with subsequent reports at weekly intervals. All raw data and copies of nine-track tapes have been retained by the Test Directorate and the contractors for any further analysis that may be desired.

The total data package assembled by the Test Directorate was ultimately returned to the 6585th Test Group headquarters at Holloman AFB for detailed analysis and preparation of the test report. A full data package was supplied to the RABVAL project team for the independent evaluation presented in the next chapter. Data analysts for ADTC and each of the instrumentation contractors cooperated closely with the Test Directorate and the IDA test monitors in detecting discrepancies in data processing, and in performing the recomputations required to assure accurate instrumentation results, both absolute and relative among instrumentation systems.

## C. TEST INSTRUMENTATION

Conventional test instrumentation installed on the Eglin/ADTC range complex includes precision tracking radars and modern, high quality Contraves cinetheodolites. Both were employed in RABVAL testing. The FPS-16 radar installations provided range control, initial positioning, and air traffic safety. A radar plot for each range sortie was recorded. The cinetheodolites provided position and velocity data from 396 runs. Six sites on the Eglin B-70 range, the primary site used,[7] provided at least three cameras tracking on each pass (and usually more).

Prior to testing, ADTC estimated that accuracies between 0.5 and 1.25 feet in position and between 0.2 and 0.5 foot-per-second in velocity could be achieved by triangulation if six sites were available. As noted below, these accuracy predictions were valid.

Two anticipated limitations inherent in cinetheodolite data reduction led to the procurement of additional precision instrumentation. First, the time lag required in the

6. Early in the test program, considerable reliance was placed on the inherently less accurate radar data as a quick check on system performance because it could be produced in 1-2 days. As confidence was gained in system capability, radar data were used less.

7. Because of the requirement for two arrays on some test sorties and some conflicts in range scheduling, three other ranges in the Eglin complex were occasionally used: B-75, C-52, and C-72, with four cinetheodolite sites. Since none of these was equipped with the additional special instrumentation procured for RABVAL, the bulk of the data was obtained on B-70.

production and analysis of photographic data, which can vary from 1 day to several weeks, suggested the need for a near real-time instrumentation system accurate enough to determine immediately whether ongoing testing was within tolerable analytical limits. The McDonnell-Douglas Corporation was awarded a contract by DDR&E to provide its Mobile Automatic Laser Tracking (MALT) System.[8] A base position, with the required visual array of calibration targets, was established by precision survey on the B-70 range to provide laser beam tracking through the release point with a predicted accuracy of 0.5 foot in position and 0.75 foot-per-second in velocity. It was expected that laser tracking data would be available within 24 hours or less. However, difficulties encountered by McDonnell-Douglas in data handling caused unexpected delays up to several days. Data transmission between Eglin and the McDonnell-Douglas data production site by telephone proved unreliable, resulting in mail and hand deliveries. Some time advantage was realized in data production, but the more significant value of the laser tracker proved to be the competitive cross-check it provided on cinetheodolite performance and data reduction.

The second limitation in theodolite and laser tracking that required additional test instrumentation was the inherent accuracy of these two systems. A major objective of the demonstration test was to determine the absolute accuracy of the BSS. Simulations indicated that the BSS was likely to be significantly more accurate than either the cinetheodolites or the laser tracker could measure with acceptable statistical confidence.[9] For this reason, a contract was let with DBA Systems, Inc., to provide ballistic camera analysis of a limited number of runs for calibration of the external instrumentation systems and verification of the absolute accuracy of the BSS. By triangulating against a star background with two or three ballistic cameras, accuracies one or two orders of magnitude superior to the other three systems can be achieved. For the conditions and profiles being tested, this permits use of ballistic camera data as if it had no error. Because of installation and weather delays, only 19 runs (17 by the laser tracker) were recorded simultaneously by all instrumentation, late in the test series. While less than desired, this number was considered an acceptable statistical sample.

Every attempt was made to optimize all instrumentation positioning for tracking the aircraft as it passed through the release point (Figure 5).[10] To conserve resources and minimize data reduction time, cinetheodolite tracking was restricted to 3 miles prior and 2

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8. The MALT system is a self-contained optical tracking system installed in a mobile van. A technical description of the system and operational details are contained in References 9 and 10.

9. The RMS radial prediction error of less than 20 feet in the ground plane expected of the BSS would indicate accuracies at the release point of less than 5 feet in position and 0.5 foot-per-second in velocity. A common criterion for test instrumentation is that it be 10 times more accurate than the system tested. Cinetheodolites and the laser tracker can approach this criterion for position accuracy under ideal circumstances, but even at best cannot meet the velocity measurement accuracy requirements.

10. The location of the laser tracker to the right of the run-in path caused some difficulty, particularly at low altitudes, in tracking the A-6, which was constrained by power problems to carry the pod on the left wing blocking the line of sight. For this reason, and because some of the sorties were flown on other ranges where only cinetheodolite instrumentation was available, the laser tracker provided data for only 206 of the 396 cinetheodolite passes.

miles beyond the central transponder. The only restriction on laser tracking was the acquisition and the visual lock-on range permitted by atmospheric visibility and aircraft altitude, which varied from run to run. The ballistic cameras provided coverage approximately 1,000 feet (about 1 second) along the track at the release point.

In order to achieve the degree of accuracy required for effective demonstration of BSS capability and to compare the relative accuracies of the three external instrumentation systems, common timing, common coordinates, and a common tracking reference point were required. IRIG B provided the precision time reference. The common coordinates selected were east, north, and up (X, Y, and Z, respectively) in a tangent plane coordinate system with its origin at the center transponder. The common reference point selected for the data reduction was the center of gravity of the pod's IMU. All instrumentation measured the position and velocity of the reference point with respect to the origin of the coordinate system.

The three external instrumentation systems all tracked points on the aircraft other than the center of gravity of the IMU, requiring translation of the point tracked to the reference point. The theodolites tracked the nose of the aircraft. The ballistic camera runs made at night tracked an aircraft running light. The position and velocity of the nose (or running light) were determined with respect to the center transponder, then translated to the center of gravity of the IMU along the velocity vector (corrected for wind) with a lever arm of approximately 40 feet for the F-111 and 20 feet for the A-6. On all flights, the laser system tracked the retroreflector mounted on the pod approximately 2 feet from the center of gravity of the IMU, and translated using the roll, yaw, and pitch angles determined from the IMU. Ballistic cameras tracked a strobe light in the pod about 5 feet from the center of gravity of the IMU. The position of the strobe light filament was translated to the center of gravity of the IMU using the roll, yaw, and pitch angles of the IMU. The mathematical rationale for translation to the common reference used by each of the data reducing activities (ADTC, McDonnell-Douglas, and DBA Systems) can be found in References 11, 12, and 13, respectively.

For convenience in presentation, all data have been rotated to the conventional downrange/crossrange/up coordinate system customarily used in bomb scoring. Table 6 shows the absolute values of the six position and velocity parameters recorded by each of the instrumentation systems, including the BSS, for the 19 runs in which all instrumentation systems achieved valid simultaneous data. (The laser system achieved valid data on only 17 runs.) In Table 7, laser, cinetheodolite, and BSS data are differenced with respect to the ballistic camera. Differenced data for the BSS are included in the table for potential future uses of the BSS as a range instrumentation system. It was determined from detailed analysis of the ballistic camera results that they were at least an order of magnitude better than the other instrumentation systems, and hence can be used as a standard of measurement.

As expected, Table 7 indicates that the cinetheodolites and laser tracker can measure accurately enough for conventional bomb scoring. Position measurements are excellent, but velocities do not appear to be as good as those measured by the BSS.

*Table 6. Comparitive Measurements of Release Point Position and Velocity for BSS Demonstration Runs*

| Speed* (kt) | Position (ft) Down-range | Position (ft) Cross-range | Position (ft) Altitude | Velocity (ft/sec) Down-range | Velocity (ft/sec) Cross-range | Velocity (ft/sec) Vertical | Position (ft) Down-range | Position (ft) Cross-range | Position (ft) Altitude | Velocity (ft/sec) Down-range | Velocity (ft/sec) Cross-range | Velocity (ft/sec) Vertical |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Ballistic Cameras** | | | | | | **Cinetheodolites** | | | | | |
| 400 | -2948.7 | -475.0 | 1508.3 | 674.84 | -6.72 | -9.60 | -2948.9 | -474.9 | 1510.4 | 674.63 | -6.05 | -9.74 |
| 400 | -3189.8 | -467.0 | 1643.5 | 684.72 | -.92 | 10.66 | -3190.0 | -467.6 | 1645.7 | 684.50 | -.85 | 11.50 |
| 400 | -3106.6 | -617.1 | 1396.2 | 699.03 | 6.73 | .54 | -3107.1 | -616.5 | 1398.0 | 698.57 | 6.90 | 1.24 |
| 400 | -3091.1 | -513.8 | 1442.9 | 716.03 | 19.00 | -5.08 | -3091.6 | -513.2 | 1444.8 | 715.59 | 18.77 | -4.76 |
| 400 | -3191.6 | -709.2 | 1514.1 | 696.67 | 8.15 | -.34 | -3191.9 | -708.6 | 1515.4 | 696.29 | 8.17 | -.11 |
| 400 | -3177.8 | -680.8 | 1474.4 | 696.70 | 6.00 | -2.73 | -3178.5 | -680.2 | 1476.0 | 696.29 | 5.63 | -3.50 |
| 400 | -3300.5 | -474.7 | 1442.0 | 688.66 | 10.03 | 11.97 | -3300.9 | -474.5 | 1443.7 | 688.63 | 9.73 | 12.79 |
| 400 | -3149.0 | -543.5 | 1436.4 | 715.25 | 6.62 | -10.43 | -3149.3 | -542.6 | 1438.0 | 714.96 | 6.62 | -9.96 |
| 400 | -3184.1 | -442.5 | 1463.1 | 701.40 | 20.55 | 2.53 | -3184.6 | -441.8 | 1464.6 | 700.93 | 20.63 | 2.93 |
| 400 | -2994.9 | -480.5 | 1484.3 | 702.61 | -3.22 | 10.90 | -2995.6 | -482.5 | 1486.8 | 702.43 | -3.32 | 10.01 |
| 400 | -3173.7 | -570.5 | 1511.7 | 692.95 | 2.14 | -24.84 | -3174.2 | -572.0 | 1514.9 | 692.61 | 2.04 | -24.59 |
| 400 | -3199.2 | -502.2 | 1549.6 | 694.33 | -2.36 | 7.09 | -3199.8 | -504.1 | 1552.3 | 694.21 | -2.57 | 6.80 |
| 400 | -3174.9 | -522.3 | 1548.3 | 701.83 | .36 | 8.16 | -3175.5 | -523.8 | 1551.0 | 701.62 | .47 | 8.17 |
| 600 | -3082.9 | -559.7 | 1553.6 | 1031.94 | .49 | 1.88 | -3082.3 | -560.2 | 1556.2 | 1031.44 | .55 | 1.54 |
| 600 | -2909.3 | -474.8 | 1535.3 | 1047.15 | -1.24 | 2.07 | -2908.7 | -475.3 | 1538.3 | 1047.02 | -1.38 | 1.56 |
| 600 | -2835.3 | -577.7 | 1558.0 | 1034.52 | 2.62 | 12.39 | -2834.8 | -577.9 | 1560.4 | 1034.42 | 2.23 | 11.65 |
| 600 | -3056.2 | -512.7 | 1559.0 | 1029.98 | -3.23 | 5.92 | -3055.5 | -512.9 | 1561.5 | 1029.48 | -3.18 | 6.47 |
| 600 | -2864.0 | -589.6 | 1585.2 | 1038.29 | -5.10 | 4.87 | -2863.2 | -589.8 | 1587.8 | 1038.25 | -5.08 | 4.43 |
| 600 | -3179.6 | -536.9 | 1579.3 | 1036.82 | 1.82 | 13.21 | -3179.0 | -537.2 | 1582.0 | 1036.49 | 1.83 | 12.60 |
| | **Laser Tracker** | | | | | | **Bomb Scoring System** | | | | | |
| 400 | -2949.3 | -475.0 | 1509.1 | 674.54 | -6.25 | -9.49 | -2949.2 | -469.0 | 1509.2 | 674.85 | -6.92 | -9.39 |
| 400 | -3190.3 | -467.5 | 1644.2 | 684.49 | -.84 | 11.13 | -3190.4 | -459.4 | 1642.9 | 684.69 | -1.40 | 11.08 |
| 400 | -3106.5 | -617.4 | 1397.0 | 698.76 | 7.00 | .72 | -3106.6 | -612.2 | 1390.2 | 698.84 | 6.49 | .95 |
| 400 | -3091.0 | -514.2 | 1443.4 | 715.88 | 19.05 | -4.93 | -3090.5 | -513.3 | 1438.5 | 715.86 | 18.79 | -4.70 |
| 400 | -3191.4 | -709.4 | 1514.7 | 696.26 | 8.16 | -.05 | -3191.3 | -707.6 | 1511.2 | 696.47 | 8.09 | -.12 |
| 400 | -3177.9 | -681.3 | 1475.1 | 696.72 | 6.25 | -3.12 | -3179.4 | -679.3 | 1469.9 | 696.62 | 5.99 | -2.30 |
| 400 | -3300.8 | -475.4 | 1442.4 | 688.97 | 9.61 | 12.36 | -3302.4 | -472.8 | 1436.8 | 688.86 | 9.61 | 12.74 |
| 400 | -3148.9 | -543.5 | 1436.8 | 714.99 | 6.50 | -10.43 | -3150.3 | -541.7 | 1435.3 | 715.15 | 6.58 | -10.05 |
| 400 | -3183.9 | -442.8 | 1463.6 | 701.50 | 20.72 | 2.41 | -3185.6 | -444.3 | 1460.5 | 701.33 | 20.51 | 3.02 |
| 400 | -2994.8 | -480.5 | 1484.6 | 702.37 | -3.15 | 10.84 | -2994.5 | -479.9 | 1481.9 | 702.52 | -3.50 | 10.79 |
| 400 | -3173.3 | -571.1 | 1512.2 | 692.92 | 2.66 | -24.90 | -3173.7 | -569.9 | 1510.0 | 692.81 | 1.93 | -25.03 |
| 400 | -3198.8 | -503.1 | 1550.5 | 694.18 | -1.42 | 7.07 | -3198.6 | -501.9 | 1547.0 | 694.21 | -2.50 | 7.02 |
| 400 | -3174.6 | -522.3 | 1548.5 | 701.61 | -.03 | 8.45 | -3174.9 | -522.6 | 1546.4 | 701.66 | .43 | 8.04 |
| 600 | 0.0 | -0.0 | 0.0 | 0.00 | -0.00 | 0.00 | -3078.2 | -560.1 | 1559.2 | 1031.79 | -.06 | -.22 |
| 600 | -2909.3 | -474.9 | 1535.8 | 1047.88 | -1.01 | 1.95 | -2906.1 | -476.5 | 1540.9 | 1047.37 | -1.12 | .06 |
| 600 | -2835.4 | -578.4 | 1558.4 | 1035.35 | 2.99 | 11.99 | -2833.6 | -578.8 | 1560.2 | 1034.82 | 2.36 | 11.62 |
| 600 | -3056.2 | -513.9 | 1559.7 | 1030.11 | -3.32 | 6.13 | -3053.4 | -512.7 | 1564.0 | 1029.81 | -3.58 | 3.94 |
| 600 | 0.0 | -0.0 | 0.0 | 0.00 | -0.00 | 0.00 | -2862.3 | -589.9 | 1589.6 | 1038.53 | -5.35 | 3.93 |
| 600 | -3179.7 | -537.6 | 1579.7 | 1037.48 | 1.77 | 13.40 | -3176.6 | -536.7 | 1587.2 | 1036.77 | 1.52 | 11.11 |

*Other profile conditions include 1,500-foot altitude and 500-foot offset.

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Table 7. *Difference Between Release Point Data of Cinetheodolites/Laser Tracker/ BSS and Ballistic Camera*

| Speed* (kt) | Cinetheodolites Minus Ballistic Camera | | | | | | Laser Tracker Minus Ballistic Camera | | | | | | BSS Minus Ballistic Camera | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Position (ft) | | | Velocity (ft/sec) | | | Position (ft) | | | Velocity (ft/sec) | | | Position (ft) | | | Velocity (ft/sec) | | |
| | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical | Down-range | Cross-range | Altitude | Down-range | Cross range | Vertical |
| 400 | -.1 | .1 | 2.1 | -.20 | .68 | -.14 | -.6 | .0 | .8 | -.30 | .47 | .11 | -.5 | 6.1 | .9 | .02 | -.19 | .21 |
| 400 | -.2 | -.6 | 2.2 | -.22 | .06 | .83 | -.4 | -.5 | .7 | -.23 | .08 | .46 | -.5 | 7.6 | -.6 | -.03 | -.48 | .41 |
| 400 | -.4 | .5 | 1.8 | -.46 | .17 | .69 | .1 | -.3 | .8 | -.27 | .27 | .17 | -.0 | 4.9 | -6.0 | -.19 | -.24 | .40 |
| 400 | -.5 | .6 | 1.9 | -.45 | -.23 | .32 | .1 | -.4 | .6 | -.16 | .06 | .15 | .6 | .5 | -4.4 | -.18 | -.21 | .38 |
| 400 | -.3 | .6 | 1.3 | -.38 | .02 | .22 | .3 | -.2 | .6 | -.42 | .01 | .28 | .4 | 1.6 | -2.8 | -.21 | -.06 | .21 |
| 400 | -.6 | .6 | 1.6 | -.42 | -.38 | -.77 | -.1 | -.6 | .7 | .01 | .25 | -.39 | -1.5 | 1.4 | -4.5 | -.08 | -.02 | .43 |
| 400 | -.4 | .2 | 1.6 | -.03 | -.30 | .82 | -.3 | -.7 | .4 | .32 | -.42 | .39 | -2.0 | 1.8 | -5.3 | .21 | -.42 | .77 |
| 400 | -.4 | 1.0 | 1.6 | -.29 | .01 | .47 | .1 | .0 | .5 | -.25 | -.11 | -.00 | -1.4 | 1.8 | -1.1 | -.09 | -.03 | .38 |
| 400 | -.5 | .7 | 1.5 | -.47 | .07 | .40 | .2 | -.3 | .5 | .09 | .16 | -.12 | -1.5 | -1.8 | -2.6 | -.07 | -.04 | .49 |
| 400 | -.7 | -1.5 | 2.5 | -.18 | -.10 | -.88 | .1 | .0 | .4 | -.24 | .08 | -.05 | .4 | .6 | -2.4 | -.09 | -.28 | -.10 |
| 400 | -.5 | -1.4 | 3.2 | -.34 | -.09 | .24 | .4 | -.6 | .5 | -.02 | .53 | -.07 | -.0 | .6 | -1.7 | -.14 | -.20 | -.20 |
| 400 | -.6 | -1.9 | 2.7 | -.12 | -.20 | -.29 | .4 | -.9 | .8 | -.15 | .95 | -.02 | .5 | .3 | -2.6 | -.12 | -.13 | -.07 |
| 400 | -.6 | -1.4 | 2.7 | -.21 | .11 | .01 | .3 | .0 | .2 | -.22 | -.38 | .29 | .1 | -.3 | -2.0 | -.17 | .08 | -.12 |
| 600 | .7 | -.6 | 2.6 | -.50 | .07 | -.34 | † | † | † | † | † | † | 4.7 | -.4 | 5.6 | -.15 | -.54 | -2.10 |
| 600 | .6 | -.5 | 2.9 | -.13 | -.14 | -.51 | -.1 | -.1 | .4 | .73 | .22 | -.12 | 3.2 | -1.7 | 5.6 | .21 | .11 | -2.01 |
| 600 | .6 | -.2 | 2.4 | -.10 | -.39 | -.74 | -.0 | -.7 | .5 | .84 | .37 | -.40 | 1.7 | -1.1 | 2.3 | .31 | -.26 | -.77 |
| 600 | .7 | -.2 | 2.6 | -.50 | .06 | .54 | -.1 | -1.2 | .7 | .13 | -.09 | .20 | 2.7 | -.0 | 5.0 | -.17 | -.35 | -1.99 |
| 600 | .8 | -.1 | 2.3 | -.04 | .02 | -.44 | † | † | † | † | † | † | 1.7 | -.2 | 4.4 | .24 | -.24 | -.94 |
| 600 | .6 | -.3 | 2.7 | -.33 | .01 | -.61 | -.2 | -.7 | .4 | .66 | -.05 | .19 | 3.0 | .2 | 8.0 | -.06 | -.30 | -2.10 |
| RMS | .5 | .9 | 2.3 | .32 | .23 | .55 | .3 | .5 | .6 | .38 | .35 | .24 | 1.9 | 2.7 | 4.1 | .16 | .27 | 1.03 |

*Other profile conditions include 1,500-foot altitude and 500-foot offset.

†Laser failed to track.



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Chapter II

# ACCURACY RESULTS

This chapter presents the accuracy results obtained for the BSS from the demonstration tests. Results are presented for the simulated bomb drop tests, for the actual bomb drop tests, and for the self-survey tests. For the simulated bomb drop tests, external instrumentation was used to measure release points and these measurements were then compared with the BSS measurements of the same points. These tests constituted the bulk of the testing program and the bulk of the data. For the actual bomb drop tests, a few inert bombs were actually dropped, either 2,000-pound Mk 84 low-drag bombs or 500-pound Mk 82 retarded (high-drag) bombs. Each resulting impact was then compared with BSS prediction. For the self-survey tests, BSS surveys of transponder locations were compared with the known locations as determined by accurate optical surveys.

The simulated bomb drop tests had two purposes: to verify BSS scoring accuracy in its role as a bomb scoring system, and to verify the position and velocity measurement accuracies for other possible uses of the system. The general goal was 20 feet root mean square (RMS) radial scoring error in the impact plane as determined by the error of release point position and velocity measurement. This goal was included in the contract along with a pullup maneuver that could be used in order to achieve this goal if necessary. In design of the tests, however, it was decided to emphasize level flightpaths since that was judged to be more typical of the tactics of radar bombing. The goal of 20 feet was chosen because an accuracy was needed that was significantly better than most bombing systems and because preliminary design studies indicated that accuracies on the order of 20 feet were achievable. If lesser accuracies of 30 to 40 feet were achieved, it would not significantly degrade the utility of BSS for scoring most bombing systems. (See Appendix B for the effect of scoring accuracy on measuring a bombing system accuracy.)

The self-survey accuracy goal was 2 feet RMS in each horizontal axis and 5 feet RMS in the vertical axis, in a three-axis coordinate system that is aligned to true north to within 3 milliradians.

Section A contains results of the simulated bomb drop tests, both with the very accurate ballistic camera instrumentation and with the less accurate cinetheodolite and laser tracker instrumentation. Section B contains results of actual bomb drop tests, and Section C the self-survey test results.

## A. SIMULATED BOMB DROP TESTS

Three kinds of external instrumentation were used to measure the release point position and velocity: cinetheodolites, a laser tracker, and ballistic cameras. The ballistic cameras were the most accurate by one or two orders of magnitude. For practical purposes, ballistic camera errors can be ignored in comparison with the BSS, cinetheodolite, or laser tracker errors (see Chapter I). It is more difficult, time consuming, and costly to reduce ballistic camera data, however, so ballistic cameras were used as additional instrumentation for only a few passes (19 passes out of approximately 400). Only two flight profiles were examined by the ballistic cameras because of the difficulty in reorienting the cameras. The number of passes is small but, because the ballistic camera data requires fewer qualifications than cinetheodolite and laser tracker data and provides a better measurement of BSS performance, it is useful to present it in detail first. Also, because the data set is small, detailed analytical procedures can be presented that are only alluded to for the larger data set.

### 1. Simulated Bomb Drop Tests Measured by Ballistic Cameras

#### a. Release Point Accuracies

The coordinate system used by the BSS is a tangent plane set of coordinates with its origin located at the central transponder. The basic coordinates used by the BSS are east, north, and up denoted by X, Y, and Z, respectively. Only after weapon impact calculation does the BSS rotate results into a downrange miss and a crossrange miss from target. (The downrange direction is defined by the ground track heading, and crossrange is defined as positive to the right.) The conventional system of downrange and crossrange is better for presentation, however, because it normalizes the effects of different headings on different test ranges (the array was always oriented to the expected flightpath for each range). For this reason most data have been rotated and presented in downrange, crossrange, and altitude unless otherwise specified.

Table 8 shows the basic measurements of release point position and velocity by the BSS and by the ballistic cameras for the 19 passes. Thirteen passes are at 400 knots (675 ft/sec) and six passes are at 600 knots (1,000 ft/sec). All passes have an offset of 500 feet (i.e., the flightpath passes 500 feet to one side of the central transponder, evidenced by the approximate 500-foot crossrange measurement for each pass).[1] All passes have an altitude above the central transponder of 1,500 feet, and all have a release point appropriate for a high-drag bomb.[2]

1. A 500-foot offset is a more difficult problem for the BSS than if the flightpath merely goes directly over the central transponder (altitude measurements are easier for a direct flyover). It was felt to be more conservative to emphasize a case where there was some error in the bomb run rather than a perfect bomb run.

2. It should be noted that for the ballistic camera passes the pilots were guided to the appropriate release point by ground radar and ground optical control and not by the aircraft systems.

*Table 8. BSS and Ballistic Camera Measurements of Release Point Position and Velocity*

| Pass No. * | Bomb Scoring System | | | | | | Ballistic Camera | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Position (ft)† | | | Velocity (ft/sec) | | | Position (ft) | | | Velocity (ft/sec) | | |
| | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical |
| 1 | -2949.2 | -469.0 | 1509.2 | 674.85 | -6.92 | -9.39 | -2948.7 | -475.0 | 1508.3 | 674.84 | -6.72 | -9.60 |
| 2 | -3190.4 | -459.4 | 1642.9 | 684.69 | -1.40 | 11.08 | -3189.8 | -467.0 | 1643.5 | 684.72 | -.92 | 10.66 |
| 3 | -3106.6 | -612.2 | 1390.2 | 698.84 | 6.49 | .95 | -3106.6 | -617.1 | 1396.2 | 699.03 | 6.73 | .54 |
| 4 | -3090.5 | -513.3 | 1438.5 | 715.86 | 18.79 | -4.70 | -3091.1 | -513.8 | 1442.9 | 716.03 | 19.00 | -5.08 |
| 5 | -3191.3 | -707.6 | 1511.2 | 696.47 | 8.09 | -.12 | -3191.6 | -709.2 | 1514.1 | 696.67 | 8.15 | -.34 |
| 6 | -3179.4 | -679.3 | 1469.9 | 696.62 | 5.99 | -2.30 | -3177.8 | -680.8 | 1474.4 | 696.70 | 6.00 | -2.73 |
| 7 | -3302.4 | -472.8 | 1436.8 | 688.86 | 9.61 | 12.74 | -3300.5 | -474.7 | 1442.0 | 688.66 | 10.03 | 11.97 |
| 8 | -3150.3 | -541.7 | 1435.3 | 715.15 | 6.58 | -10.05 | -3149.0 | -543.5 | 1436.4 | 715.25 | 6.62 | -10.43 |
| 9 | -3185.6 | -444.3 | 1460.5 | 701.33 | 20.51 | 3.02 | -3184.1 | -442.5 | 1463.1 | 701.40 | 20.55 | 2.53 |
| 10 | -2994.5 | -479.9 | 1481.9 | 702.52 | -3.50 | 10.79 | -2994.9 | -480.5 | 1484.3 | 702.61 | -3.22 | 10.90 |
| 11 | -3173.7 | -569.9 | 1510.0 | 692.81 | 1.93 | -25.03 | -3173.7 | -570.5 | 1511.7 | 692.95 | 2.14 | -24.84 |
| 12 | -3198.6 | -501.9 | 1547.0 | 694.21 | -2.50 | 7.02 | -3199.2 | -502.2 | 1549.6 | 694.33 | -2.36 | 7.09 |
| 13 | -3174.9 | -522.6 | 1546.4 | 701.66 | .43 | 8.04 | -3174.9 | -522.3 | 1548.3 | 701.83 | .36 | 8.16 |
| 14 | -3078.2 | -560.1 | 1559.2 | 1031.79 | -.06 | -.22 | -3082.9 | -559.7 | 1553.6 | 1031.94 | .49 | 1.88 |
| 15 | -2906.1 | -476.5 | 1540.9 | 1047.37 | -1.12 | .06 | -2909.3 | -474.8 | 1535.3 | 1047.15 | -1.24 | 2.07 |
| 16 | -2833.6 | -578.8 | 1560.2 | 1034.82 | 2.36 | 11.62 | -2835.3 | -577.7 | 1558.0 | 1034.52 | 2.62 | 12.39 |
| 17 | -3053.4 | -512.7 | 1564.0 | 1029.81 | -3.58 | 3.94 | -3056.2 | -512.7 | 1559.0 | 1029.98 | -3.23 | 5.92 |
| 18 | -2862.3 | -589.9 | 1589.6 | 1038.53 | -5.35 | 3.93 | -2864.0 | -589.6 | 1585.2 | 1038.29 | -5.10 | 4.87 |
| 19 | -3176.6 | -536.7 | 1587.2 | 1036.77 | 1.52 | 11.11 | -3179.6 | -536.9 | 1579.3 | 1036.82 | 1.82 | 13.21 |

*Passes 1-13 are at speeds of 400 knots and passes 14-19 at 600 knots.

†Downrange heading for these ballistic camera passes is defined as 237 degrees, and crossrange is positive to the right. Downrange, crossrange, and altitude are measured relative to the central transponder.

Table 9 contains the difference between the BSS measurement and the ballistic camera measurement—the BSS error. The RMS error for each coordinate is given for 13 passes at 400 knots and 6 passes at 600 knots separately.

A BSS subprogram known as the Kalman filter estimates the accuracy achieved by the BSS (i.e., the BSS estimates its own error). This accuracy estimation is a necessary part of the proper functioning of the subprogram but, as a useful byproduct, these estimates are made available to the BSS user. This subprogram is responsible, among other things, for deciding how much weight to attach to incoming sensor measurements (position and velocity from the inertial navigation system, range and range rate from the transponders, and altitude from the barometer). The Kalman filter uses a model of sensor accuracy and compares the accuracy of new sensor inputs with the accuracy in position and velocity already achieved on the pass due to processing earlier sensor inputs. At the end of the pass, as another byproduct, the BSS uses this estimate of achieved position and velocity accuracy to estimate the accuracy of scoring ground impact. This is done by using appropriate impact

*Table 9. BSS Measurement Minus Ballistic Camera Measurement of Release Point Position and Velocity*

| Pass No. * | BSS Minus Ballistic Camera (BSS error) | | | | | |
|---|---|---|---|---|---|---|
| | Position (ft) | | | Velocity (ft/sec) | | |
| | Downrange | Crossrange | Altitude | Downrange | Crossrange | Vertical |
| 1 | –.5 | 6.1 | .9 | .02 | –.19 | .21 |
| 2 | –.5 | 7.6 | –.6 | –.03 | –.48 | .41 |
| 3 | –.0 | 4.9 | –6.0 | –.19 | –.24 | .40 |
| 4 | .6 | .5 | –4.4 | –.18 | –.21 | .38 |
| 5 | .4 | 1.6 | –2.8 | –.21 | –.06 | .21 |
| 6 | –1.5 | 1.4 | –4.5 | –.08 | –.02 | .43 |
| 7 | –2.0 | 1.8 | –5.3 | .21 | –.42 | .77 |
| 8 | –1.4 | 1.8 | –1.1 | –.09 | –.03 | .38 |
| 9 | –1.5 | –1.8 | –2.6 | –.07 | –.04 | .49 |
| 10 | .4 | .6 | –2.4 | –.09 | –.28 | –.10 |
| 11 | –.0 | .6 | –1.7 | –.14 | –.20 | –.20 |
| 12 | .5 | .3 | –2.6 | –.12 | –.13 | –.07 |
| 13 | .1 | –.3 | –2.0 | –.17 | .08 | –.12 |
| RMS | 1.0 | 3.2 | 3.3 | .14 | .23 | .37 |
| 14 | 4.7 | –.4 | 5.6 | –.15 | –.54 | –2.10 |
| 15 | 3.2 | –1.7 | 5.6 | .21 | .11 | –2.01 |
| 16 | 1.7 | –1.1 | 2.3 | .31 | –.26 | –.77 |
| 17 | 2.7 | –.0 | 5.0 | –.17 | –.35 | –1.99 |
| 18 | 1.7 | –.2 | 4.4 | .24 | –.24 | –.94 |
| 19 | 3.0 | .2 | 8.0 | –.06 | –.30 | –2.10 |
| RMS | 3.0 | .9 | 5.4 | .21 | .33 | 1.75 |

*Passes 1-13 are at speeds of 400 knots and passes 14-19 at 600 knots.

sensitivites to the release point accuracies.

Table 10 contains a comparison of BSS error with BSS estimated error in the east, north, and up coordinate system–the system used on the BSS printout. For the two different flight conditions or "profiles" used (400 and 600 knots) and for each coordinate, the table contains the RMS error of the BSS, the RMS BSS estimate of accuracy, and the ratio of BSS error to BSS estimate. Aside from the BSS estimate being about 30 percent too small, there is a fair correspondence between BSS error and BSS estimate of that error, except for altitude and vertical velocity at 600 knots. The reason for this latter discrepancy is not presently known, but it can be observed that the altitude error and vertical velocity error at 600 knots have negative correlation so that at least for scoring purposes the errors partially compensate.

*Table 10. Comparison of BSS Error With BSS Error Estimates*

| | Position (ft) | | | Velocity (ft/sec) | | |
|---|---|---|---|---|---|---|
| | East | North | Up | East | North | Up |
| 400-Knot Passes (13) | | | | | | |
| RMS of BSS error | 1.7 | 2.9 | 3.3 | .19 | .19 | .37 |
| RMS of BSS error estimate | 1.5 | 2.0 | 2.5 | .12 | .18 | .32 |
| BSS error/BSS error estimate | 1.1 | 1.5 | 1.3 | 1.6 | 1.1 | 1.2 |
| 600-Knot Passes (6) | | | | | | |
| RMS of BSS error | 2.3 | 2.2 | 5.4 | .26 | .29 | 1.75 |
| RMS of BSS error estimate | 1.5 | 1.8 | 2.7 | .18 | .27 | .32 |
| BSS error/BSS error estimate | 1.5 | 1.2 | 2.0 | 1.4 | 1.1 | 5.5 |

b. Scoring Accuracy

**Scoring Accuracy Derived From Position and Velocity Measurement.** This section examines the consequences of BSS error in measuring the release point for impact scoring. To do this, the *sensitivity* to each BSS error in the impact plane is needed. The BSS routinely computes these sensitivites for each release using the conditions of that release (e.g., speed, altitude, climb angle) and includes them in the printout. These computations have been verified for a variety of conditions and are used in these analyses.

The scoring error for each pass can be determined by multiplying these sensitivities times the achieved BSS errors as measured by external instrumentation. Some BSS errors contribute to downrange miss and others contribute to crossrange miss. If the downrange and crossrange groups are summed separately for each pass, the net downrange and crossrange scoring errors can be determined.

Since the number of ballistic camera passes is small, it was desirable to use each pass twice, once as a high-drag bomb pass and once as a low-drag bomb pass. This was done by calculating the additional sensitivities required. The BSS was flown containing low-drag ballistic data for 17 of the 19 passes, so that 17 supplemental high-drag sensitivities and 2 supplemental low-drag sensitivities were calculated. The only artificiality of this procedure is that the release point standoff for all passes was that appropriate for a high-drag release. When viewed as a low-drag release, the release point is closer to the center of the array than normal (about 3,000 versus 6,000 feet). This should improve the scoring accuracy about 25 percent compared to a profile with the normal release point standoff for a low-drag bomb.

Table 11 shows impact prediction errors due to the BSS errors for each pass. These errors are obtained by multiplying the BSS errors of Table 9 by the appropriate sensitivities for a delivery. For the high-drag bomb, for example, the 0.9-foot altitude position error of pass No. 1 of Table 9 multiplied by the sensitivity to that error of 0.6 ft/ft produces the

*Table 11. Impact Prediction Errors Due to BSS Errors*

| Pass No.* | Downrange Group (ft) | | | | | Crossrange Group (ft) | | | Radial (ft) |
|---|---|---|---|---|---|---|---|---|---|
| | Downrange Position | Altitude Position | Downrange Velocity | Vertical Velocity | Total | Crossrange Position | Crossrange Velocity | Total | |
| **BSS Impact Error Using High-Drag Ballistics** | | | | | | | | | |
| 1 | -.5 | .5 | .2 | .7 | .9 | 6.1 | -2.5 | 3.6 | 3.7 |
| 2 | -.5 | -.3 | -.4 | 1.3 | .0 | 7.6 | -6.1 | 1.5 | 1.5 |
| 3 | -.0 | -3.2 | -2.4 | 1.3 | -4.3 | 4.9 | -3.0 | 1.9 | 4.7 |
| 4 | .6 | -2.3 | -2.2 | 1.2 | -2.8 | .5 | -2.6 | -2.1 | 3.5 |
| 5 | .4 | -1.5 | -2.6 | .7 | -3.1 | 1.6 | -.7 | .9 | 3.2 |
| 6 | -1.5 | -2.4 | -1.0 | 1.4 | -3.6 | 1.4 | -.2 | 1.2 | 3.8 |
| 7 | -2.0 | -2.8 | 2.6 | 2.4 | .3 | 1.8 | -5.3 | -3.5 | 3.5 |
| 8 | -1.4 | -.6 | -1.2 | 1.2 | -2.0 | 1.8 | -.4 | 1.4 | 2.4 |
| 9 | -1.5 | -1.4 | -1.0 | 1.5 | -2.2 | -1.8 | -.5 | -2.3 | 3.2 |
| 10 | .4 | -1.3 | -1.1 | -.3 | -2.3 | .6 | -3.6 | -2.9 | 3.7 |
| 11 | -.0 | -.9 | -1.7 | -.6 | -3.3 | .6 | -2.6 | -1.9 | 3.8 |
| 12 | .5 | -1.4 | -1.5 | -.2 | -2.6 | .3 | -1.7 | -1.3 | 2.9 |
| 13 | .1 | -1.0 | -2.2 | -.4 | -3.5 | -.3 | 1.0 | .7 | 3.6 |
| RMS | 1.0 | 1.7 | 1.7 | 1.2 | 2.7 | 3.2 | 2.9 | 2.1 | 3.4 |
| 14 | 4.7 | 3.1 | -1.9 | -6.8 | -.9 | -.4 | -6.7 | -7.2 | 7.2 |
| 15 | 3.2 | 3.1 | 2.6 | -6.5 | 2.4 | -1.7 | 1.4 | -.3 | 2.4 |
| 16 | 1.7 | 1.3 | 3.8 | -2.5 | 4.3 | -1.1 | -3.2 | -4.3 | 6.1 |
| 17 | 2.7 | 2.8 | -2.1 | -6.4 | -3.0 | -.0 | -4.3 | -4.3 | 5.3 |
| 18 | 1.7 | 2.5 | 3.0 | -3.0 | 4.1 | -.2 | -3.0 | -3.3 | 5.3 |
| 19 | 3.0 | 4.5 | -.7 | -6.8 | -.0 | .2 | -3.7 | -3.5 | 3.5 |
| RMS | 3.0 | 3.0 | 2.5 | 5.7 | 2.9 | 0.9 | 4.1 | 4.3 | 5.2 |
| **BSS Impact Error Using Low-Drag Ballistics** | | | | | | | | | |
| 1 | -.5 | 2.0 | .2 | 4.4 | 6.1 | 6.1 | -1.9 | 4.2 | 7.4 |
| 2 | -.5 | -1.4 | -.3 | 8.7 | 6.5 | 7.6 | -4.7 | 2.8 | 7.1 |
| 3 | -.0 | -12.9 | -1.9 | 8.5 | -6.3 | 4.9 | -2.3 | 2.5 | 6.8 |
| 4 | .6 | -9.5 | -1.7 | 8.0 | -2.6 | .5 | -2.0 | -1.5 | 3.0 |
| 5 | .4 | -6.1 | -2.0 | 4.5 | -3.2 | 1.6 | -.6 | 1.1 | 3.4 |
| 6 | -1.5 | -9.7 | -.3 | 9.1 | -2.9 | 1.4 | -.2 | 1.3 | 3.1 |
| 7 | -2.0 | -11.3 | 2.0 | 16.3 | 5.0 | 1.8 | -4.1 | -2.3 | 5.5 |
| 8 | -1.4 | -2.4 | -.9 | 7.9 | 3.3 | 1.8 | -.3 | 1.5 | 3.6 |
| 9 | -1.5 | -5.6 | -.7 | 10.4 | 2.6 | -1.8 | -.4 | -2.2 | 3.4 |
| 10 | .4 | -5.1 | -.9 | -2.2 | -7.7 | .6 | -2.8 | -2.1 | 8.0 |
| 11 | -.0 | -3.8 | -1.3 | -4.1 | -9.2 | .6 | -2.0 | -1.4 | 9.3 |
| 12 | .5 | -5.7 | -1.2 | -1.5 | -7.8 | .3 | -1.3 | -1.0 | 7.9 |
| 13 | .1 | -4.2 | -1.7 | -2.6 | -8.5 | -.3 | .7 | .5 | 8.5 |
| RMS | 1.0 | 7.1 | 1.3 | 7.9 | 6.0 | 3.2 | 2.3 | 2.1 | 6.3 |
| 14 | 4.7 | 12.2 | -1.4 | -41.4 | -25.9 | -.4 | -4.9 | -5.4 | 26.5 |
| 15 | 3.2 | 12.2 | 1.9 | -39.5 | -22.2 | -1.7 | 1.0 | -.7 | 22.2 |
| 16 | 1.7 | 5.0 | 2.8 | -15.1 | -5.6 | -1.1 | -2.4 | -3.5 | 6.6 |
| 17 | 2.7 | 11.0 | -1.5 | -39.1 | -26.9 | -.0 | -3.2 | -3.2 | 27.1 |
| 18 | 1.7 | 9.7 | 2.2 | -18.5 | -4.9 | -.2 | -2.2 | -2.5 | 5.5 |
| 19 | 3.0 | 17.4 | -.5 | -41.3 | -21.4 | .2 | -2.7 | -2.5 | 21.6 |
| RMS | 3.0 | 11.8 | 1.9 | 34.4 | 20.0 | 0.9 | 3.0 | 3.3 | 20.3 |

*Passes 1-13 are at speeds of 400 knots and passes 14-19 at 600 knots.

0.5-foot downrange partial error found in Table 11 for pass No. 1. Summing the partial errors of the downrange group gives 0.9-foot total downrange error for that pass. The crossrange error is 3.6 feet, which together with the downrange error makes a radial error of 3.7 feet. One of the purposes for including this table is to show the relative importance of each of the BSS error sources. The RMS error for each source is indicated at the bottom of the columns. It can be seen that the sources are relatively "balanced" in the sense that they all contribute roughly the same amount of error. Some errors compensate each other (e.g., the crossrange position and velocity errors at 400 knots). For the 400- and 600-knot passes, the RMS radial error is 3.4 and 5.1 feet, respectively.

For low-drag bombs, Table 11 shows that the dominant errors are the altitude and the vertical velocity errors. The effects of these errors have a negative correlation so they tend to cancel. The cancellation is quite good at 400 knots, but at 600 knots the effects of the large vertical velocity error is not cancelled and a substantial scoring error results. For the 400- and 600-knot passes, the RMS radial error is 6.3 and 20.3 feet, respectively.

A scoring accuracy estimate for each pass is calculated by the BSS using the previously mentioned sensitivites and estimates of release point accuracy. On the printout, scoring accuracy is shown as the "downrange estimating error" and the "crossrange estimating error."[3] These can be considered as standard deviations for these two directions. An estimate of RMS radial error can be obtained from the root sum square of these two estimating errors. It should be emphasized that BSS error estimates are not perfect. It is based on the Kalman filter's model of the world and is not as definitive as measurement by external instrumentation. It is useful, however, to show how close the BSS estimates approach reality. When the BSS is used in some location other than an instrumented range, a great deal of reliance must be placed on the BSS accuracy estimates.

Since 17 of the 19 ballistic camera passes were flown with low-drag ballistics, a good sample of BSS estimates of scoring accuracy was available for low-drag passes. However, there were 20 nonballistic camera passes made with identical flight profiles at 400 knots in which high-drag ballistics were used. Since the estimates usually vary only about 20 percent from pass to pass, the average estimate for these nonballistic camera passes can be used as estimates for the ballistic camera passes. There is no similar sample available for 600 knots, however.

Table 12 shows a summary of the measured scoring accuracies and compares it with the average BSS estimates of scoring accuracy. It can be seen that the BSS estimated accuracy came close to the measured accuracy for all flight profiles except for the 600-knot low-drag profile. The BSS does not calculate an accuracy for vertical velocity. The BSS assumes a priori the vertical velocity accuracy to be 0.316 ft/sec and does not include it as a state in the Kalman filter.[4] In estimating scoring accuracy, the BSS uses this assumed

3. Figure 17 of Chapter III shows an actual BSS printout.

4. This was done because design simulations indicated that a Kalman filter would not significantly improve the basic accuracy of the baro-damped vertical velocity channel of the INS.

*Table 12. BSS Scoring Accuracy on Ballistic Camera Passes*

| Flight Profile* | No. of Passes | Ground Impact Scoring Accuracy (RMS Radial Error) (ft) | |
|---|---|---|---|
| | | Measured Position and Velocity Errors | BSS Error Estimate |
| High-Drag Ballistics | | | |
| 400 Knots | 13 | 3.4 | 4.4† |
| 600 Knots | 6 | 5.2 | Not Available |
| Low-Drag Ballistics | | | |
| 400 Knots | 13 | 6.3 | 6.6** |
| 600 Knots | 6 | 20.3 | 9.5 |

*Other profile conditions include 1,500-foot altitude and 500-foot offset.

†This estimate is not taken from ballistic camera passes, but from a large sample of 22 passes flown with identical profile.

**This value is based on available data from 11 of the 13 passes made at this profile.

0.316 ft/sec vertical velocity accuracy, which is much too small for the measured 1.75 ft/sec error at 600 knots. Since the sensitivity for the vertical velocity for the profile in question is approximately 30, small BSS errors can have significant effects.

It is important to point out what assumptions are implied in the above procedure of obtaining scoring accuracy by multiplying release point errors by sensitivities to those errors. It assumes that the weapon impact subprogram of the BSS computes the trajectory correctly, if given the correct inputs. This is a good assumption and the only controversial point is whether the program uses the best weapon parameters (e.g., assumed ejection velocity, assumed drag coefficients). It also assumes no separation anomalies or ballistic dispersion. These random effects, of course, do exist and degrade the ability of any scoring or bombing system to predict the fall of a given bomb. More will be said about these subjects in Section B concerning actual bomb drop results. Finally, it assumes no air data measurement errors, which is the subject of the next subsection.

**Scoring Accuracy Including Air Data Measurements.** Air data are measured at the release point for the purpose of determining air density and wind vector. The air density is assumed to vary with altitude with the standard lapse rate. The wind, however, is assumed to be constant all the way to the ground. Both of these are common assumptions for bombing systems, although some bombing systems now use a statistical tapering off of wind velocity between the aircraft and the ground. This section addresses the accuracy of air density and wind vector measurements and the effect of these measurement errors on scoring accuracy.

*Table 13. Air Data Measurement Accuracies*

| Quantity | Measured Accuracy RMS* |
|---|---|
| Used in Impact Calculation | |
| Wind Vector | 4.8 knots along track<br>4.0 knots cross track |
| Air Density | 0.33 percent |
| Others Listed in Printout | |
| Barometric Altitude | 76 feet† |
| Airspeed | 2.1 knots |
| Air Temperature | 0.7 degree C |
| Sideslip | 0.43 degree** |

*The wind vector measurements were obtained by comparison with A-6E values on 48 passes at 400 knots. All other accuracy measurements are contractor measurements and are included here for completeness.

†At low altitudes and excluding a bias due to a nonstandard assumption of sea level pressure of 30.4 inches of Hg instead of 29.92 inches of Hg.

**Obtained by comparing readings from pods flown simultaneously on opposite wings.

Wind vector air data measurements were checked against the A-6E air data system as shown in Table 13. The other air data shown in the table were checked by the contractor (Ref. 14).

There was a sample of 48 passes at 400 knots for which it was possible to compare BSS wind vector with the A-6E bomb/nav system determination of wind vector. The results of comparison were 4.8 knots along track and 4.0 knots cross track. The accuracies expected a priori were on the order of 3 knots for the A-6E,[5] and on the order of 2 knots along track and 3 to 5 knots cross track for the BSS (Ref. 14).[6] Since the comparison includes the errors of the A-6E along the BSS, the comparison accuracies should be regarded as an upper limit for the BSS.

The accuracy of the remaining items in Table 13 were measured or estimated by the contractor and are included here for completeness.

The barometric altitude is based cn a standard atmosphere except that sea level pressure is assumed to be 30.4 inches of Hg instead of the standard 29.92. Near sea level, 1 inch of Hg is equivalent to about 1,000 feet of pressure altitude. If, for example, the barometric pressure for a given day is 29.9 inches of Hg, then the barometric altitude will read high by about 500 feet (corresponding to 0.5 inch of Hg). This bias was put in to assure that the Kalman filter would initialize at a higher altitude than true altitude so that the filter could converge more safely from "above" rather than from "below."

Sideslip is a measurement of the lateral angular deviation of the airflow past the probe from the normal direction of straight ahead. The bow wave from the airplane,

5. Tom Zehner, Grumman Aircraft Corporation, private communication.

6. The contractor estimates (Table 13) of 2.1-knot airspeed error and 0.43 degree sideslip error correspond to wind measurement errors along track of 2.1 knots, and cross track of 500 knots x sin 0.43 degrees = 3.0 knots at 400 knots, and 600 knots x sin 0.43 degree = 4.5 knots at 500 knots.

however, comes across the probe and appears to the probe as a sideslip. Consequently, a large bias (2 to 4 degrees) has to be subtracted from the raw instrument readings by the computer. This bias was determined by flying two pods simultaneously on opposite wings and comparing sideslip readings. This bias is stored in the computer in parametric form so that different biases can be used for different types of aircraft.

Table 14 shows the effect on scoring accuracy when the wind vector measurement error expected by the contractor is included (the air density effect is negligible). The effect on the low-drag bombs is of little consequence, but the effect on high-drag bombs is substantial, especially from an altitude as high as 1,500 feet.

*Table 14. BSS Scoring Accuracy on Ballistic Camera Passes Including Air Data Errors*

| Flight Profile* | No. of Passes | Ground Impact Scoring Accuracy (RMS Radial Error) (ft) | |
|---|---|---|---|
| | | Measured Position and Velocity Errors | Including Air Data Errors† |
| High-Drag Ballistics | | | |
| 400 Knots | 13 | 3.4 | 51.8 |
| 600 Knots | 6 | 5.2 | 77.8 |
| Low-Drag Ballistics | | | |
| 400 Knots | 13 | 6.3 | 6.5 |
| 600 Knots | 6 | 20.3 | 21.1 |

*Other profile conditions include 1,500-foot altitude and 500-foot offset.

†Based on contractor estimated accuracy for wind measurements of 2.1 knots downrange, and 3.0 and 4.5 knots crossrange at 400 and 600 knots, respectively.

### 2. Simulated Bomb Drop Tests Measured by Cinetheodolites and Laser Tracker

Most of the testing was done using cinetheodolites and a laser tracker as external instrumentation. The accuracy of instrumentation was not as good as the ballistic cameras, but it was generally adequate for verifying bomb scoring capability. The ease of data reduction allowed many more passes to be examined (363 versus 19), which allowed a greater variety of profiles to be examined.

The term *external instrumentation* refers in this section to:

- Cinetheodolites—if only cinetheodolite data were available (188 passes).
- Laser tracker—if only laser tracker data were available (5 passes).
- Average of the two—if both cinetheodolite and laser tracker data were available (170 passes).

Measurements of BSS error using the above external instrumentation contains errors from the external instrumentation as well as the BSS. This especially degrades measurement of BSS velocity accuracies. Table 15 shows a comparison of all the various instrumentations for the 17 ballistic camera runs that were common to all of them.[7] For most of the discussion that follows, the inaccuracies of the external instrumentation are ignored. In some cases, the BSS accuracies presented are actually upper limits rather than true reflections of BSS performance.

Table 16 shows the release point position and velocity accuracies measured by the external instrumentation. Both the high-drag and low-drag profiles are shown.[8] Several profiles were deliberately chosen with altitudes lower and offsets somewhat larger than normal operational use in order to provide profiles that would explore the performance limits of the BSS. Higher altitudes and smaller offsets present more favorable geometry so the BSS is more accurate than for the reference profile.

Table 17 summarizes the net RMS radial scoring error for each of the profiles. The table also contains the BSS estimates of scoring accuracy. In general, the BSS estimate is a good indicator of accuracy. When the estimate is small or large, the RMS scoring error is small or large, respectively.

The limits of the system were found on the first profile of Table 17. Occasionally, the BSS estimated the altitude to be too low, sometimes by as much as 50 feet. This produces the large RMS altitude error in Table 16. This problem occurred on approximately 6 out of the 15 passes listed. The cause of the problem is not known for certain, but it is certainly exacerbated by the bad geometry of 200-foot altitude and 500-foot offset. If the 6 passes are removed from the sample of 15, the scoring accuracy becomes 43 feet and the BSS estimated 45 feet, which is closer to the accuracy expected from the original design studies. The BSS should probably not be used for level passes lower than 300 to 400 feet that have an offset greater than 300 to 400 feet.

The 0-foot offset profile in the table does not exhibit any of the problems of the 500-foot offset profile. Even though its altitude is only 200 feet, the geometry is good and consequently the scoring accuracy is as good as anticipated. The 1,000-foot offset profile should theoretically have a worse scoring accuracy than the 500-foot offset passes, but by chance, it had fewer problems than the first profile and so appears to be more accurate. The accuracy is close to that anticipated in design studies. If a pullup maneuver is added to the 1,000-foot offset profile, the scoring accuracy improves (44 versus 73 feet). The pullup maneuver was performed immediately after release and was a 3- to 4-g pullup to a 30-degree climb that leveled out at some convenient altitude such as 10,000 feet. The vertical motion and the higher view of the array after release provided by this maneuver allowed better

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7. Although it is possible to discern biases in the cinetheodolite and laser tracker data for the conditions of the ballistic camera passes (see Chapter I), the extrapolation of these biases to other profiles is not known. Therefore, no attempt was made to remove any instrumentation biases.

8. A high-drag profile is one with an appropriate release point standoff from target for high-drag bombs and with high-drag ballistics used in the BSS; similarly for low-drag profile.

Table 15. Comparison of Instrumentation on Ballistic Camera Passes (RMS Difference Between Instrumentation)

| Instrumentation Comparison | Position (ft) | | | Velocity (ft/sec) | | | High-Drag Scoring Accuracy (ft) | | | Low-Drag Scoring Accuracy (ft) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical | Down-range | Cross-range | Radial | Down-range | Cross-range | Radial |
| 400-Knot Passes (13) | | | | | | | | | | | | |
| BSS Minus Ballistic Camera | 1.0 | 3.2 | 3.3 | .14 | .23 | .37 | 2.7 | 2.1 | 3.4 | 6.0 | 2.1 | 6.3 |
| BSS Minus Cinetheodolites | 0.9 | 3.4 | 5.1 | .23 | .33 | .46 | 1.9 | 2.6 | 3.2 | 11.7 | 2.1 | 11.6 |
| BSS Minus Laser | .9 | 3.4 | 3.8 | .15 | .50 | .36 | 2.7 | 4.9 | 5.6 | 7.0 | 3.8 | 7.9 |
| BSS Minus Average of Cinetheodolites and Laser | 0.8 | 3.4 | 4.4 | .14 | .36 | .35 | 1.8 | 2.7 | 3.2 | 8.7 | 2.1 | 9.0 |
| Cinetheodolites Minus Ballistic Camera | 0.5 | 1.0 | 2.1 | .32 | .26 | .55 | 3.5 | 3.5 | 5.0 | 11.8 | 2.8 | 12.2 |
| Laser Minus Ballistic Camera | 0.3 | 0.5 | 0.6 | .23 | .38 | .24 | 2.6 | 4.7 | 5.3 | 4.9 | 3.6 | 6.1 |
| Average of Cinetheodolites and Laser Minus Ballistic Camera | 0.2 | 0.6 | 1.3 | .25 | .24 | .37 | 2.7 | 2.9 | 4.0 | 8.1 | 2.3 | 8.4 |
| 600-Knot Passes (4) | | | | | | | | | | | | |
| BSS Minus Ballistic Camera | 2.7 | 1.0 | 5.6 | .21 | .27 | 1.80 | 2.9 | 3.5 | 4.6 | 20.7 | 2.7 | 20.9 |
| BSS Minus Cinetheodolites | 2.1 | 0.8 | 3.2 | .34 | .29 | 1.65 | 4.0 | 3.1 | 5.1 | 22.6 | 2.2 | 22.8 |
| BSS Minus Laser | 2.8 | 1.1 | 5.1 | .54 | .37 | 1.85 | 6.6 | 4.6 | 8.1 | 27.1 | 3.5 | 27.3 |
| BSS Average of Cinetheodolites and Laser | 2.5 | 0.9 | 4.1 | .12 | .25 | 1.74 | 2.1 | 2.9 | 3.6 | 24.2 | 2.1 | 24.3 |
| Cinetheodolites Minus Ballistic Camera | 0.6 | 0.3 | 2.7 | .31 | .21 | .61 | 2.5 | 2.8 | 3.7 | 9.1 | 2.1 | 9.4 |
| Laser Minus Ballistic Camera | 0.1 | 0.8 | 0.5 | .65 | .22 | .25 | 7.9 | 2.7 | 8.3 | 6.8 | 2.0 | 7.1 |
| Average of Cinetheodolites and Laser Minus Ballistic Camera | 0.3 | 0.5 | 1.6 | .27 | .03 | .39 | 3.0 | 0.6 | 3.0 | 5.3 | 0.6 | 5.3 |

*Table 16. Accuracies of Release Point Position and Velocity (RMS of the Difference Between External Instrumentation and BSS)*

| Flight Profile Conditions | | | | | | Position (ft) | | | Velocity (ft/sec) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Altitude (ft AGL) | Speed (kt) | Offset (ft) | No. of Trans-ponders | Maneuver | No. of Passes | Down-range | Cross-range | Altitude | Down-range | Cross-range | Vertical |
| **High-Drag Simulated Bomb Drops** | | | | | | | | | | | |
| 200 | 400 | 500 | 4 | Level | 15 | 2.0 | 8.5 | 25.0 | .42 | .93 | .81 |
| 200 | 400 | 0 | 4 | Level | 22 | 11.9 | 10.9 | 5.1 | .55 | .85 | .83 |
| 200 | 400 | 1,000 | 4 | Level | 14 | 4.7 | 5.5 | 24.0 | .30 | .69 | 1.28 |
| 200 | 400 | 1,000 | 4 | Pullup* | 6 | 1.6 | 1.6 | 19.4 | .32 | .66 | 1.98 |
| 200 | 600 | 500 | 4 | Level | 8 | 7.1 | .1 | 12.2 | .30 | .98 | .76 |
| 500 | 400 | 500 | 4 | Level | 17 | 3.5 | 11.0 | 7.7 | .32 | .45 | 1.02 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 1.6 | 4.1 | 3.9 | .41 | .52 | .86 |
| 500† | 480/525 | 500 | 2 | Level | 15 | 1.1 | 6.9 | 6.6 | .20 | .52 | .70 |
| 500† | 480/525 | 500 | 3 | Level | 23 | 1.2 | 4.7 | 5.4 | .35 | .50 | 1.03 |
| **Low-Drag Simulated Bomb Drops** | | | | | | | | | | | |
| 500 | 400 | 500 | 4 | Level | 36 | 1.7 | 4.2 | 4.9 | .30 | .52 | .92 |
| 500 | 600 | 500 | 4 | Level | 18 | 3.2 | 8.6 | 9.6 | .45 | .98 | 1.73 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 2.4 | 4.6 | 8.6 | .35 | .35 | 1.05 |
| 5,000 | 400 | 500 | 4 | Level | 22 | 4.1 | 9.9 | 12.4 | .31 | .39 | .79 |
| 5,000 | 500 | 500 | 4 | Level | 10 | 7.8 | 8.3 | 23.0 | .65 | .40 | 1.84 |
| 10,000 | 400 | 500 | 4 | Level | 21 | 11.3 | 8.3 | 16.8 | .48 | .31 | .92 |
| 500 | 400 | 500 | 4 | 10 deg climb | 12 | 2.2 | 10.3 | 4.9 | .81 | .92 | .94 |
| 500 | 400 | 500 | 4 | Pullup* | 8 | 1.7 | 3.6 | 6.2 | .22 | .70 | .95 |
| 500 | 550 | 500 | 4 | Pullup* | 12 | 1.7 | 3.8 | 4.8 | .43 | .52 | 1.03 |
| 500 | 400 | 0 | 4 | Breakaway* | 20 | 1.9 | 4.6 | 3.9 | .31 | [illegible] | .85 |
| 1,000† | 420/480 | 500 | 2 | Level | 14 | 2.0 | 9.2 | 6.3 | .43 | .26 | .82 |
| 1,000† | 420/480 | 500 | 3 | Level | 26 | 1.4 | 3.5 | 3.9 | .35 | .58 | .92 |

*After simulated release.

†Profiles in operational tests of A-6E and F-111F.

determination of release point altitude. This pullup maneuver from low altitudes could probably be used to good effect on profiles with even greater offset (e.g., 3,000 feet), but this was not tested. The 600-knot profile should have been susceptible to the same problems as the first profile, but they did not show up in the small number of runs made. The BSS estimate of error was worse than it actually achieved for this profile.

The central transponder was accidentally turned off for 2 of the 8 600-knot passes, and for 3 of the 22 0-foot offset passes with no particular ill effects. The function of the central transponder was essentially performed by the redundant downrange transponder (No. 4 in Figure 5, Chapter I). If the flightpath had not passed over that outer transponder, the accuracies would probably have been much worse.

*Table 17. BSS Scoring Accuracy (RMS of Release Point Errors Multiplied by the Sensitivity to Those Errors)*

| Flight Profile Conditions | | | | | | Ground Impact Scoring Accuracy (RMS Radial Error) (ft) | |
|---|---|---|---|---|---|---|---|
| Altitude (ft AGL) | Speed (kt) | Offset (ft) | No. of Trans-ponders | Maneuver | No. of Passes | Measured Position and Velocity Errors | BSS Error Estimates |
| **High-Drag Simulated Bomb Drops** | | | | | | | |
| 200 | 400 | 500 | 4 | Level | 15 | 101.7 | 56.8 |
| 200 | 400 | 0 | 4 | Level | 22 | 15.7 | 12.4 |
| 200 | 400 | 1,000 | 4 | Level | 14 | 73.0 | 64.8 |
| 200 | 400 | 1,000 | 4 | Pullup* | 6 | 44.3 | 22.3 |
| 200 | 600 | 500 | 4 | Level | 8 | 51.1 | 87.0 |
| 500 | 400 | 500 | 4 | Level | 17 | 16.8 | 9.7 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 9.7 | 4.4 |
| 500† | 480/525 | 500 | 2 | Level | 15 | 14.0 | 8.8 |
| 500† | 480/525 | 500 | 3 | Level | 23 | 11.9 | 7.0 |
| **Low-Drag Simulated Bomb Drops** | | | | | | | |
| 500 | 400 | 500 | 4 | Level | 36 | 15.3 | 15.3 |
| 500 | 600 | 500 | 4 | Level | 18 | 42.8 | 27.2 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 18.6 | 8.9 |
| 5,000 | 400 | 500 | 4 | Level | 22 | 14.2 | 5.8 |
| 5,000 | 500 | 500 | 4 | Level | 10 | 18.6 | 7.3 |
| 10,000 | 400 | 500 | 4 | Level | 21 | 13.2 | 6.8 |
| 500 | 400 | 500 | 4 | 10 deg climb | 12 | 23.1 | 8.6 |
| 500 | 400 | 500 | 4 | Pullup* | 8 | 11.6 | 12.7 |
| 500 | 550 | 500 | 4 | Pullup* | 12 | 32.8 | 25.3 |
| 500 | 400 | 0 | 4 | Breakaway* | 20 | 17.3 | 12.8 |
| 1,000† | 420/480 | 500 | 2 | Level | 14 | 22.7 | 10.4 |
| 1,000† | 420/480 | 500 | 3 | Level | 26 | 17.5 | 10.4 |

*After simulated release.

†Profiles in operational tests of A-6E and F-111F.

When the altitude is increased from 200 to 500 feet, even with the 500-foot offset, the scoring accuracy improves markedly (17 *cf.* 102 feet). Increasing the altitude to 1,500 feet (profile No. 7), improves the accuracy even more (10 feet). It is interesting to note that this profile has the smallest scoring error and the smallest BSS estimate of scoring error. This was the profile selected for measurement by the ballistic cameras. Of the 22 passes listed in the table for profile 7, however, only 2 are common with the ballistic camera passes.

Profiles planned for use for the OT&E of the radar bombing systems of the A-6E and F-111 are shown next in the tables. The altitude is 500 feet, and the speeds are 480 knots for the A-6 and 525 knots for the F-111. Only two transponders were used for profile No. 8, the central transponder and an outer transponder on the same side of the aircraft as the pod (transponders Nos. 1 and either 2 or 3). For profile No. 9, three transponders were used, the central transponder and the two outer transponders on either side of the run in line (Nos. 1, 2, and 3).

The number of passes made for the first low-drag profile (No. 10) is about double the others. The 15-foot accuracy agrees well with the 15-foot BSS estimate of scoring accuracy. If the speed is increased to 600 knots, however, the accuracy degrades as shown in Table 17. This is due to poorer release point measurements by the pod (Table 16) and to increased sensitivity (about 50 percent greater).[9] Increasing altitude to 1,500, 5,000, and 10,000 feet should increase accuracy as evidenced by BSS error estimates, but the measured accuracy is about the same. Three passes not included in the table were made at 25,000 feet but with rather poor results (178 feet). This was because the altitude was much higher than the radius of the array (6,000 feet). If the array were widened for these high altitudes, the accuracy should improve again. The measured scoring errors tend to be larger than the BSS estimates for all the low-drag profiles because of the inaccuracy of the external instrumentation for measuring velocity and because of the increased sensitivity to error of low-drag bombs over high-drag bombs.

Various maneuvers were tried in profiles 17 through 19. The 10-degree climb was a release while in a climb. The post-release pullup maneuver was as described previously and is a maneuver that can be used to help the BSS determine altitude and vertical velocity when a release with bad geometry is anticipated. A breakaway was made in profile 19 by heading straight for the center transponder and making a sharp level turn after release (a maneuver sometimes used to escape bomb fragments). The fact that the BSS scores this maneuver well shows that training missions or operational testing missions need not be restricted to straight-ahead flightpaths. Although breakaways were not tested for high-drag bombs, it is expected that they would work satisfactorily because of the shorter standoff distances. Lastly, two OT&E profiles to be used in the A-6E and F-111F OT&E were flown with two and three transponders, respectively.

The effect of assumed air data errors is shown in Table 18. In general, the air data errors did not significantly degrade scoring accuracy except for the higher altitude high-drag profiles.

## B. ACTUAL BOMB DROP TESTS

As an overall test of accuracy, a few inert bombs were actually dropped, and the surveyed impacts compared with pod predictions. The miss distances between impact and prediction contain effects that are not accounted for by the BSS, separation anomalies, and

9. The cause of this unexpected degradation of measurement accuracy with higher speeds (about 550 to 600 knots) is not known. There is some suspicion, however, that it may be due to a compressibility wave crossing the air data probe at those speeds.

*Table 18. BSS Scoring Accuracy Including Air Data Errors*

| Flight Profile Conditions | | | | | | Ground Impact Scoring Accuracy (RMS Radial Error) (ft) | |
|---|---|---|---|---|---|---|---|
| Altitude (ft AGL) | Speed (kt) | Offset (ft) | No. of Trans-ponders | Maneuver | No. of Passes | Measured Position and Velocity Errors | Including Air Data Errors* |
| **High-Drag Simulated Bomb Drops** | | | | | | | |
| 200 | 400 | 500 | 4 | Level | 15 | 101.7 | 102.2 |
| 200 | 400 | 0 | 4 | Level | 22 | 15.7 | 18.5 |
| 200 | 400 | 1,000 | 4 | Level | 14 | 73.0 | 73.7 |
| 200 | 400 | 1,000 | 4 | Pullup† | 6 | 44.3 | 45.4 |
| 200 | 600 | 500 | 4 | Level | 8 | 51.1 | 53.9 |
| 500 | 400 | 500 | 4 | Level | 17 | 16.8 | 27.5 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 9.7 | 52.5 |
| 500** | 480/525 | 500 | 2 | Level | 15 | 14.0 | 31.6 |
| 500** | 480/525 | 500 | 3 | Level | 23 | 11.9 | 30.8 |
| **Low-Drag Simulated Bomb Drops** | | | | | | | |
| 500 | 400 | 500 | 4 | Level | 36 | 15.3 | 15.3 |
| 500 | 600 | 500 | 4 | Level | 18 | 42.8 | 42.8 |
| 1,500 | 400 | 500 | 4 | Level | 22 | 18.6 | 18.6 |
| 5,000 | 400 | 500 | 4 | Level | 22 | 14.2 | 14.8 |
| 5,000 | 500 | 500 | 4 | Level | 10 | 18.6 | 19.5 |
| 10,000 | 400 | 500 | 4 | Level | 21 | 13.2 | 15.3 |
| 500 | 400 | 500 | 4 | 10 deg climb | 12 | 23.1 | 23.2 |
| 500 | 400 | 500 | 4 | Pullup† | 8 | 11.6 | 11.6 |
| 500 | 550 | 500 | 4 | Pullup† | 12 | 32.8 | 32.8 |
| 500 | 500 | 0 | 4 | Breakaway† | 20 | 17.3 | 17.3 |
| 1,000** | 420/480 | 500 | 2 | Level | 14 | 22.7 | 22.7 |
| 1,000** | 420/480 | 500 | 3 | Level | 26 | 17.5 | 17.5 |

*Based on contractor estimated accuracy for wind measurements of 2.1 knots downrange, and 3.0 and 4.5 knots crossrange at 400 and 600 knots, respectively.

†After simulated release.

**Profiles in operational tests of A-6E and F-111F.

ballistic dispersion. Some of these effects are random in nature and are impossible for a BSS or for a bombing system to predict. Others are not accounted for in the present state of the art. The BSS does consider many items that would be included in dispersion for other systems; for example, pylon station used, ejection angle, roll rate, and effective side and rearward ejection velocities. For this reason, the amount of dispersion associated with the BSS is probably less than for these other systems.

The CEP for the actual bomb drop tests is approximately:

$$\sqrt{CEP_{BSS}^2 + CEP_{BD}^2} \; .$$

The $CEP_{BSS}$ is determined by comparison of release point measurements with external instrumentation and is the subject of the first part of this chapter. The actual bomb drop tests measured the above root sum square of $CEP_{BSS}$ and $CEP_{BD}$. In order to minimize the dispersion, $CEP_{BD}$, the heaviest types of high-drag and low-drag bombs were chosen, the Mk 84 2,000-pound, low-drag bomb and the Mk 82 500-pound, high-drag bomb.

### 1. Low-Drag Bombs

Table 19 contains the impact versus prediction for the low-drag bomb drops. Figures 6 and 7 show the downrange and crossrange measurements of impact, respectively, from the target versus the downrange and crossrange predictions by the BSS. Figure 8 shows bomb impacts plotted relative to prediction for each drop—the prediction in each case is the origin. As can be seen from both Tables 19 and Figure 8, the median miss distance, or CEP, is 35 feet. About half the bombs were dropped from an altitude of 1,500 feet, and the other half from 5,000 feet. Since there was not much difference in results between altitudes, both were included in the figures.

The results presented in Table 19 and Figures 6-8 represent mixed conditions, however. For drop Nos. 8, 9, and 13-16 made on 12 June and after, the contractor changed some ballistic parameters for the Mk 84 in the BSS ballistic program. The changes were:

- Ejection velocity reduced by 2 ft/sec for the outboard stations on both the F-111 and A-6 (F-111 changed from 10 to 8 ft/sec and the A-6 changed from 14 to 12 ft/sec). The net effect of the changes was to move the predicted impact point 40 feet downrange for both altitudes.

*Table 19. Impact Versus Prediction Data for Mk 84 Low-Drag Drops*

| | | | *Bomb Impact (ft)* | | *BSS Prediction (ft)* | | *Impact Minus Prediction (ft)* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Pass No.* | *Altitude (ft)* | *Aircraft* | *Down-range* | *Cross-range* | *Down-range* | *Cross-range* | *Down-range* | *Cross-range* | *Radial* |
| 1 | 1,500 | A-6 | 63 | 41 | 72 | -48 | --9 | 7 | 11 |
| 2 | 1,500 | A-6 | 119 | -49 | 101 | -50 | 18 | 1 | 18 |
| 3 | 1,500 | A-6 | 80 | -2 | 16 | -11 | 64 | 9 | 64 |
| 4 | 1,500 | A-6 | 130 | 8 | 93 | 11 | 37 | -3 | 37 |
| 5 | 1,500 | A-6 | 145 | 1 | 105 | -2 | 40 | 3 | 40 |
| 6 | 1,500 | F-111 | -62 | 35 | -128 | 48 | 66 | -13 | 67 |
| 7 | 1,500 | F-111 | 115 | 30 | 56 | 45 | 59 | -15 | 61 |
| 8 | 1,500 | A-6 | 21 | 104 | 19 | 107 | 2 | -3 | 3 |
| 9 | 1,500 | A-6 | 180 | 51 | 148 | 59 | 32 | -8 | 33 |
| | | | | | | | | *CEP* = | *37* |
| 10 | 5,000 | F-111 | 379 | 255 | 329 | 248 | 50 | 7 | 50 |
| 11 | 5,000 | A-6 | -135 | -24 | -152 | -52 | 17 | 28 | 33 |
| 12 | 5,000 | A-6 | -30 | 27 | -60 | -14 | 30 | 41 | 51 |
| 13 | 5,000 | A-6 | 284 | -111 | 279 | -99 | 5 | -12 | 13 |
| 14 | 5,000 | A-6 | 220 | 24 | 181 | 27 | 39 | -3 | 39 |
| 15 | 5,000 | A-6 | 75 | -16 | 66 | -19 | 9 | 3 | 10 |
| 16 | 5,000 | F-111 | -32 | 70 | -18 | 94 | -14 | -24 | 28 |
| | | | | | | | | *CEP* = | *33* |
| | | | | | | | *Combined* | *CEP* = | *35* |

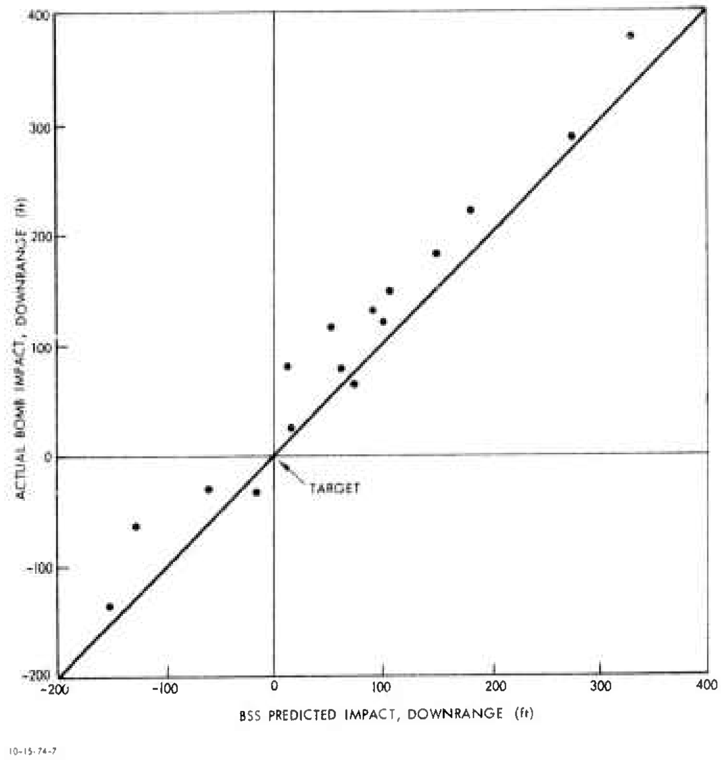


*Figure 6. Actual Impacts Versus Predicted Impacts, Downrange (Low-Drag Bombs)*

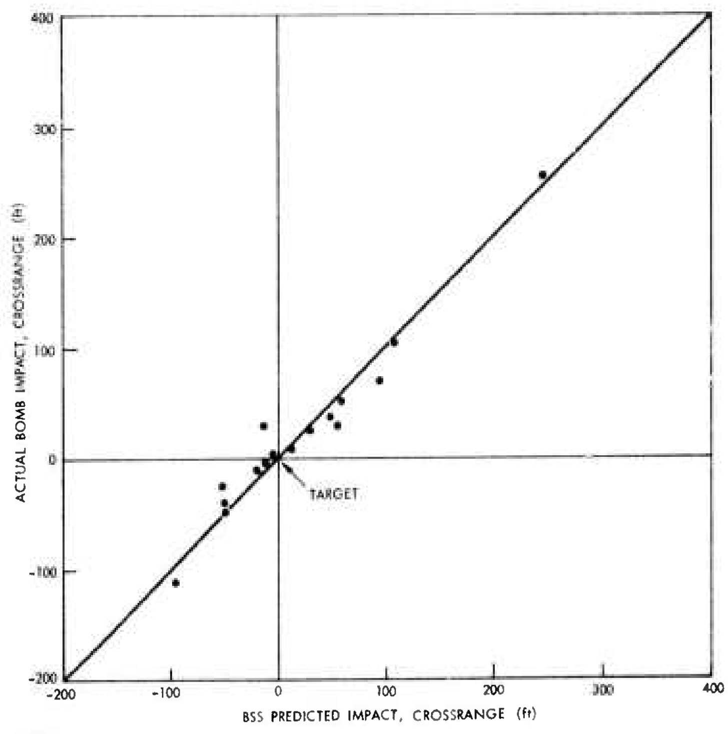


*Figure 7. Actual Impacts Versus Predicted Impacts, Crossrange (Low-Drag Bombs)*

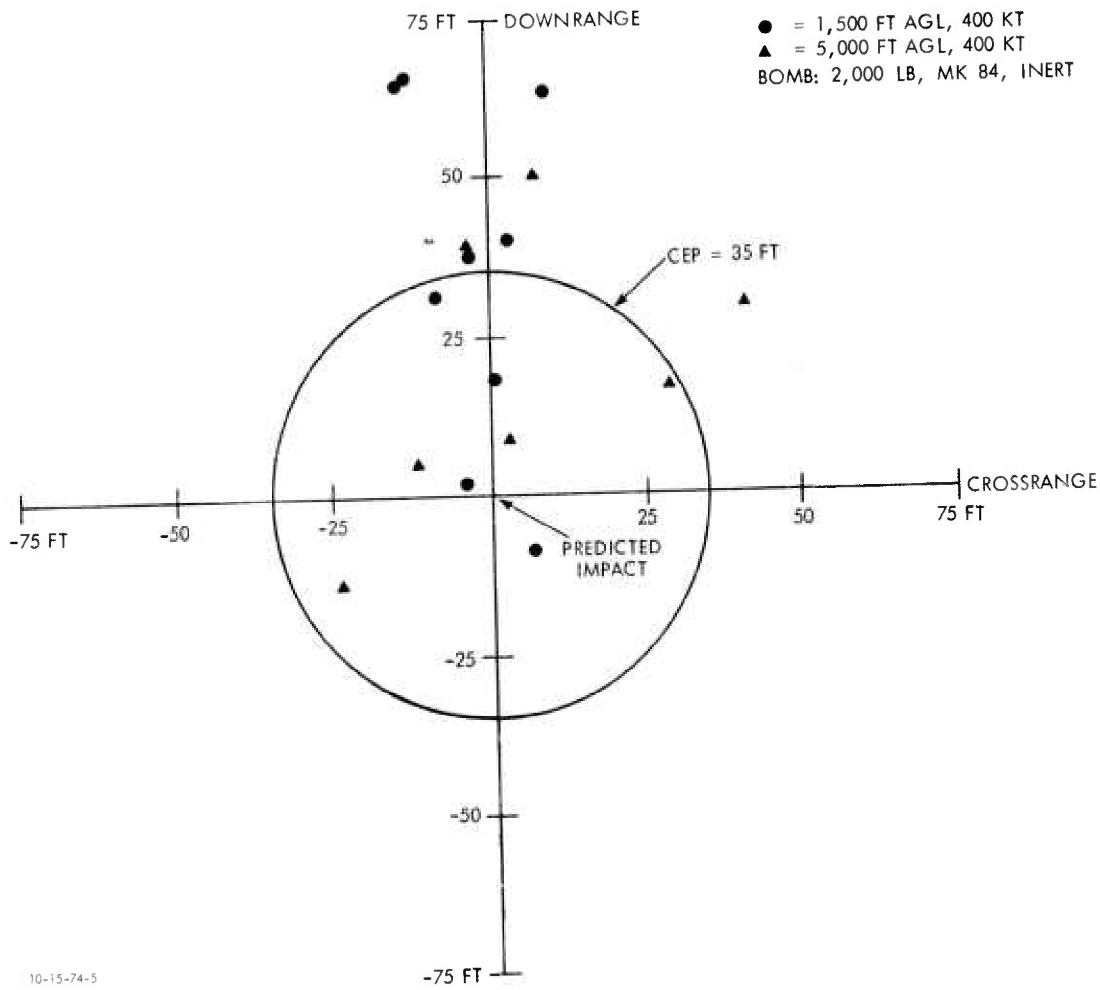


*Figure 8. Actual Impacts Relative to Predicted Impacts (Low-Drag Bombs)*

- Spin coefficient of the bomb reduced from –0.002 to 0. The net effect at this change was to move the predicted impact point to the right by 20 feet for the 5,000-foot altitude, and 6 feet for the 1,500-foot altitude.

A consistent set of data can be made by applying these corrections to the drops made prior to 12 June. These adjusted data are presented in Table 20 and in Figure 9. The results show a dramatic improvement–the CEP is 21 feet.

The BSS is an instrument of much greater accuracy than the F-111 and A-6 bombing systems so it needs greater accuracy for its ballistic parameters than the F-111 and A-6. These precision parameters were not available prior to testing and in effect had to be determined from the test itself. A small sample of "contractor learning bombs" were

*Table 20. Adjusted Data for Mk 84 Low-Drag Bomb Drops*

| Pass No. | Altitude (ft) | Aircraft | Pylon Station | Impact Minus Prediction (ft) | | |
|---|---|---|---|---|---|---|
| | | | | Down-range | Cross-range | Radial |
| 1 | 1,500 | A-6 | Inboard | -9 | 1 | 9 |
| 2 | 1,500 | A-6 | Inboard | 18 | -5 | 19 |
| 3 | 1,500 | A-6 | Outboard | 24 | 3 | 24 |
| 4 | 1,500 | A-6 | Inboard | 37 | -9 | 38 |
| 5 | 1,500 | A-6 | Outboard | 0 | -3 | 3 |
| 6 | 1,500 | F-111 | Outboard | 26 | -19 | 32 |
| 7 | 1,500 | F-111 | Outboard | 19 | -21 | 28 |
| 8 | 1,500 | A-6 | Inboard | 2 | -3 | 3 |
| 9 | 1,500 | A-6 | Outboard | 32 | -8 | 33 |
| | | | | | CEP = | 24 |
| 10 | 5,000 | F-111 | Outboard | 10 | -13 | 16 |
| 11 | 5,000 | A-6 | Inboard | 17 | 8 | 19 |
| 12 | 5,000 | A-6 | Outboard | -10 | '21 | 23 |
| 13 | 5,000 | A-6 | Inboard | 5 | -12 | 13 |
| 14 | 5,000 | A-6 | Outboard | 39 | -3 | 39 |
| 15 | 5,000 | A-6 | Outboard | 9 | 3 | 10 |
| 16 | 5,000 | F-111 | Outboard | -14 | -24 | 28 |
| | | | | | CEP = | 19 |
| | | | | | Combined CEP = | 21 |

dropped prior to those of Table 19 and some gross corrections made, but precise survey information of impact locations was not available until about 10 bombs had been dropped. By that time, the impact data showed significant biases. These biases were removed by the aforementioned corrections and, importantly, the last 6 bombs had results consistent with the first 10 after adjustment.

One of the corrections has an intuitive interpretation. For a heavy 2,000-pound bomb on an outboard station near the wing tip, part of the "kick" of the ejection cartridge should go into pushing the wing tip up instead of pushing the bomb down.

In terms of mil error measured in a plane perpendicular to the terminal flight of the bomb, the scoring accuracy CEP represents 2.4 mils before adjustment and 1.5 mils after the adjustment.

From Table 17, the BSS CEP expected from position and velocity measurements is approximately 14 feet. The degradation to 21 feet is probably due to dispersion.

Table 20 and Figure 9 infer that some further "tuning" of ballistic parameters could be done. There is still an overall downrange bias of about 13 feet, and the F-111 drops are found to be the four left-most drops with a left bias of 19 feet. For a more thorough job of tuning, a larger sample of bombs should be dropped over a larger speed-altitude envelope and a more systematic effort at parameter fitting made.

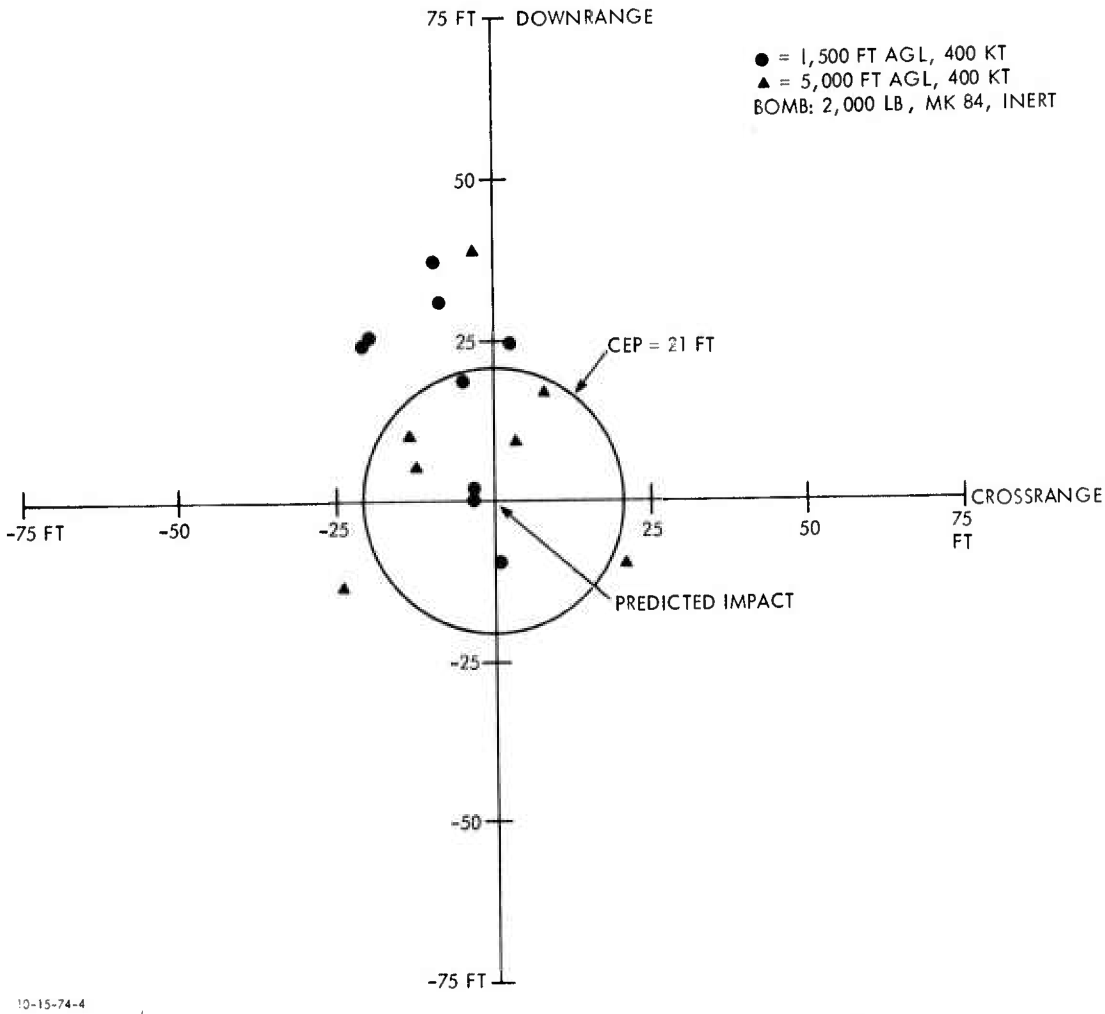


*Figure 9. Actual Impacts Relative to Predicted Impacts After Adjustment (Low-Drag Bombs)*

The BSS considers many items that are called ballistic dispersion in other systems (e.g., pylon station used, ejection angle, roll rate, effective side and rearward ejection velocities). This may be the reason why the above scoring accuracies are better than some estimates of ballistic dispersion for the Mk 84.[10]

10. The Joint Munitions Effectiveness Manual (Ref. 15) gives ballistic dispersion for the Mk 80 series of bombs as 5 mils. Consultation with ballistic analysts at NWL Dahlgren, however, indicates that dispersion for the Mk 84 should be less than 3 mils.

## 2. High-Drag Bombs

Table 21 contains the impact versus prediction data for the high-drag bomb drops. Figures 10 and 11 show the downrange and crossrange measurements, respectively, of bomb impact with respect to the target versus the BSS prediction. Figure 12 shows bomb impacts plotted with respect to BSS prediction. The median miss distance, or CEP, is 56 feet. About half the bombs were dropped from 500 feet and the rest from 1,500 feet, but these are combined in Figures 10-12.

From Table 17, the BSS CEP expected from position and velocity measurements is approximately 11 feet. Including expected air data errors, as in Table 18, the expected BSS CEP is approximately 33 feet. The degradation to 56 feet is probably due to dispersion.

The scoring accuracy is worse for high-drag bombs than for low-drag bombs because of the greater ballistic dispersion of high-drag bombs. Excluded from the above data were three bombs whose retardation fins failed to open (this typically caused 1,200-foot errors and were easily identified). It was not found necessary to adjust any ballistic parameters for the high-drag bombs. The mil accuracy corresponding to 56 feet for the high-drag bombs is 16 mils CEP.

*Table 21. Impact Versus Prediction Data for Mk 82 High-Drag Bomb Drops*

| Pass No. | Altitude (ft) | Aircraft | Bomb Impact (ft) Down-range | Bomb Impact (ft) Cross-range | BSS Prediction (ft) Down-range | BSS Prediction (ft) Cross-range | Impact Minus Prediction (ft) Down-range | Impact Minus Prediction (ft) Cross-range | Impact Minus Prediction (ft) Radial |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 500 | A-6 | −208 | 62 | −214 | 6 | 6 | 56 | 56 |
| 2 | 500 | A-6 | −238 | −4 | −229 | −12 | −9 | 8 | 12 |
| 3 | 500 | A-6 | −180 | −22 | −214 | −14 | 34 | −8 | 35 |
| 4 | 500 | F-111 | 30 | 119 | 3 | 157 | 27 | −38 | 46 |
| | | | | | | | | | CEP = 41 |
| 5 | 1,500 | F-111 | 228 | −207 | 316 | −170 | −88 | −37 | 96 |
| 6 | 1,500 | F-111 | 282 | −90 | 374 | −31 | −92 | −59 | 109 |
| 7 | 1,500 | F-111 | 362 | −72 | 337 | −41 | 25 | −31 | 40 |
| 8 | 1,500 | F-111 | 221 | −72 | 221 | −64 | 0 | −8 | 8 |
| 9 | 1,500 | F-111 | 167 | 59 | 161 | 35 | 6 | 24 | 25 |
| 10 | 1,500 | F-111 | 164 | −305 | 251 | −277 | −87 | −28 | 91 |
| 11 | 1,500 | A-6 | −2032 | 194 | −1940 | 267 | −92 | −73 | 117 |
| 12 | 1,500 | A-6 | −717 | −84 | −650 | −71 | −67 | −13 | 68 |
| 13 | 1,500 | A-6 | −1346 | 80 | −1313 | 28 | −33 | 52 | 62 |
| | | | | | | | | | CEP = 68 |
| | | | | | | | | | Combined CEP = 56 |

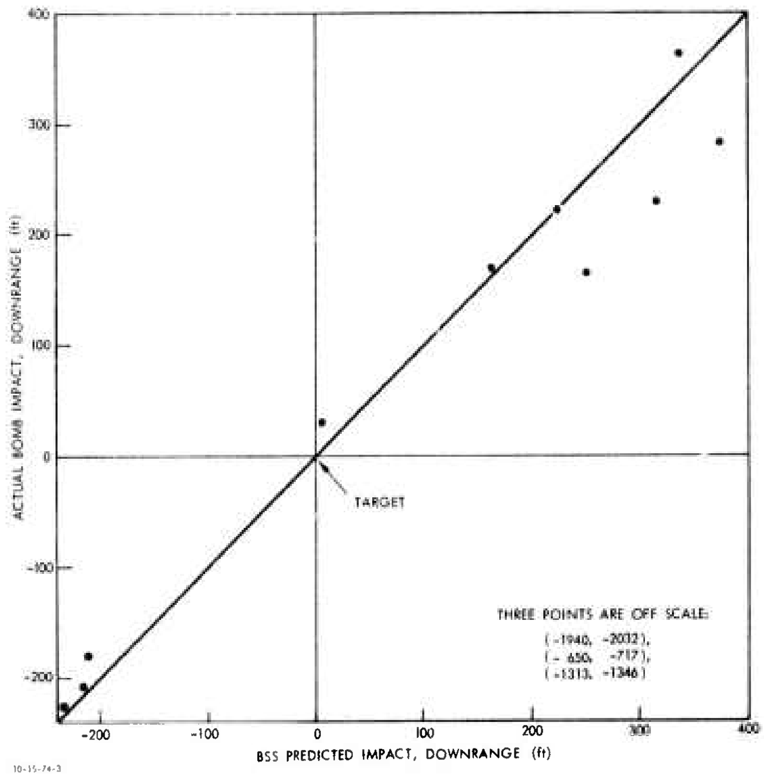


*Figure 10. Actual Impacts Versus Predicted Impacts, Downrange (High-Drag Bombs)*

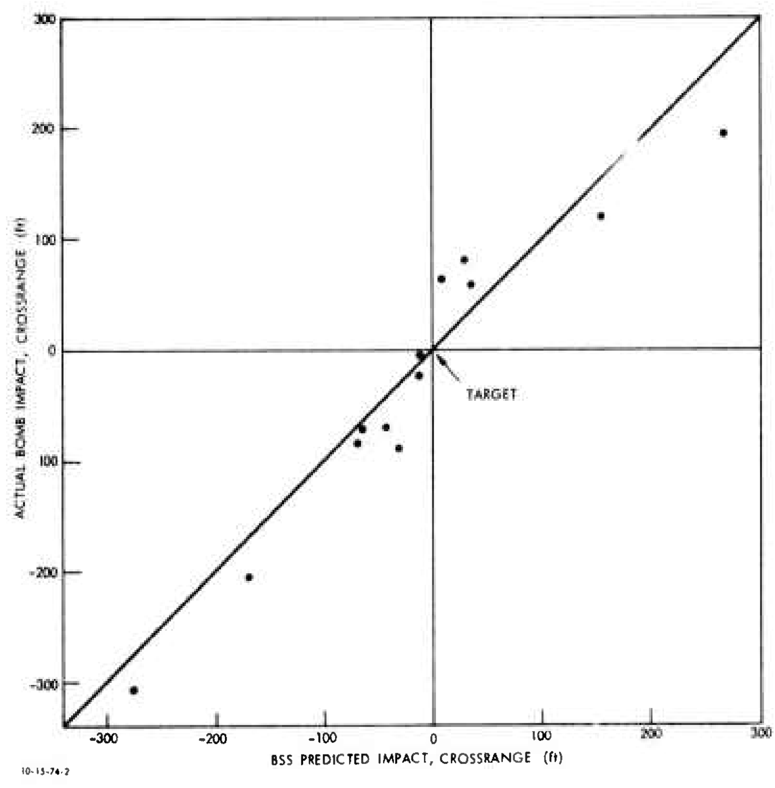


*Figure 11. Actual Impacts Versus Predicted Impacts, Crossrange (High-Drag Bombs)*

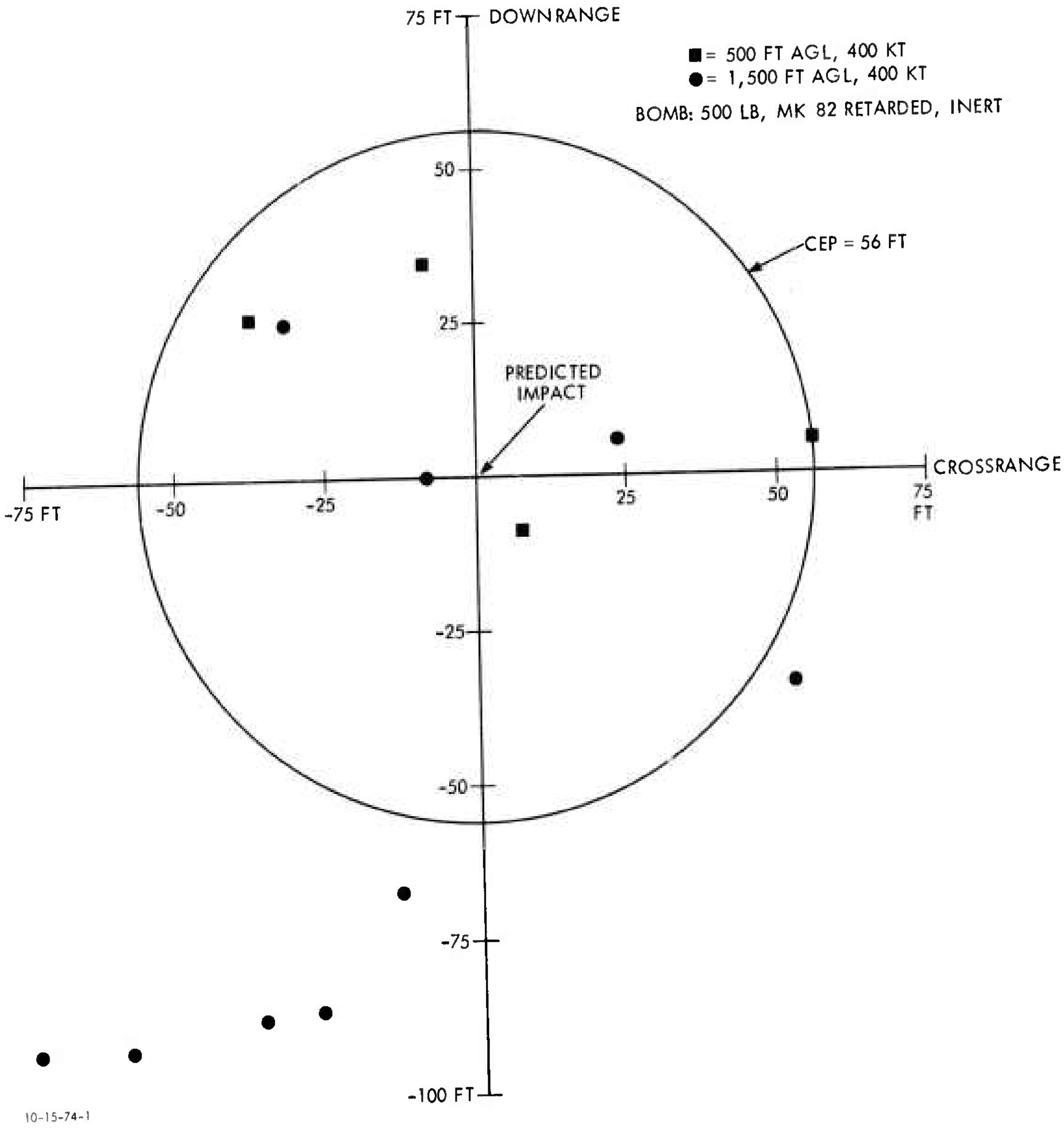


*Figure 12. Actual Impacts Relative to Predicted Impacts (High-Drag Bombs)*

## C. SELF-SURVEY TESTS

As a convenience feature, the BSS can survey its own ground transponder arrays. The survey is in an east, north, up tangent plane coordinate system with origin at the central transponder (the operation is described in Chapter I).

There are two versions of the self-survey available. The first is a faster and less accurate method that takes about 10 to 15 minutes to perform. In this method, the BSS interrogates each transponder in sequence (1 second each) and essentially tries to reduce all the survey errors "simultaneously." The second method is slower, but more accurate. The BSS takes each outer/center transponder pair and spends 5 minutes surveying just that pair. The total time taken is then 5 minutes times the number of outer transponders. This second method of survey was judged more likely to be useful operationally, so all demonstration tests used this method.

Table 22 contains the self-survey test results for the three tests accomplished. The table shows the BSS surveyed position, the true position, and the difference. The true position was determined by optical means and was accurate to better than 0.5 foot. The RMS error is 6.5, 5.9, and 8.8 feet for east, north, and up, respectively. (It is interesting that with only one exception all the up errors are positive.) Since in theory there should be no difference in accuracy for the north and east components, their errors can be averaged and the RMS errors given as 6.2, 6.2, and 8.8 feet respectively, for east, north, and up.

Table 23 shows the horizontal components of the surveys expressed in r,$\theta$ coordinates instead of east and north. The RMS error is 4.3 feet for r and 0.071 degree for $\theta$. With but

*Table 22. Test Results of Self-Survey Mode*

| Test Range | Outer Transponder Number | BSS Surveyed Position (ft) | | | True Position (ft) | | | BSS Position Minus True Position (ft) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | East | North | Up | East | North | Up | East | North | Up |
| C-52A | 1 | 1040.7 | −5911.3 | −7.3 | 1041.8 | −5908.9 | −10.8 | −1.1 | −2.4 | 3.5 |
| | 2 | 5910.6 | 1045.5 | 0.6 | 5908.9 | 1041.8 | −4.6 | 1.7 | 3.7 | 5.2 |
| | 3 | −4893.0 | 3431.1 | 19.8 | −4886.2 | 3431.4 | 16.6 | −6.8 | −.3 | 3.2 |
| B-70 | 1 | −5024.4 | −3285.3 | −6.1 | −5023.8 | −3280.4 | −15.1 | −.6 | −4.9 | 9.0 |
| | 2 | −93.6 | 6471.5 | 49.4 | −93.7 | 6465.1 | 47.9 | .1 | 6.4 | 1.5 |
| | 3 | 5350.3 | −2711.4 | −15.4 | 5352.8 | −2710.6 | −6.4 | −2.5 | −.8 | −9.0 |
| B-70 | 1 | −5034.8 | −3277.6 | −10.8 | −5023.8 | −3280.4 | −15.1 | −11.0 | 2.8 | 4.3 |
| | 2 | −79.7 | 6466.2 | 53.0 | −93.7 | 6465.1 | 47.9 | 14.0 | 1.1 | 5.1 |
| | 3 | 5349.6 | −2725.3 | 14.5 | 5352.8 | −2710.6 | −6.4 | −3.2 | −14.7 | 20.9 |
| RMS Error | | | | | | | | 6.5 | 5.9 | 8.8 |

*Table 23. Self-Survey Test Results for Horizontal Components Expressed in r, θ Coordinates*

| Test Range | Outer Transponder Number | BSS Surveyed Position Radial, r (ft) | BSS Surveyed Position Bearing, θ (deg) | True Position Radial, Δr (ft) | True Position Bearing, θ (deg) | BSS Position Minus True Position Radial, Δr (ft) | BSS Position Minus True Position Bearing, Δθ (deg) |
|---|---|---|---|---|---|---|---|
| C-52A | 1 | 6002.2 | 170.015 | 6000.0 | 170.001 | 2.2 | .014 |
| | 2 | 6002.4 | 79.969 | 6000.0 | 80.001 | 2.4 | –.032 |
| | 3 | 5976.1 | 305.039 | 5970.7 | 305.079 | 5.4 | –.040 |
| 8-70 | 1 | 6003.1 | 236.821 | 6000.0 | 236.857 | 3.1 | –.036 |
| | 2 | 6472.2 | 359.171 | 6465.8 | 359.170 | 6.4 | .001 |
| | 3 | 5998.1 | 116.875 | 6000.0 | 116.857 | –1.9 | .018 |
| 8-70 | 1 | 6007.7 | 236.936 | 6000.0 | 236.857 | 7.7 | .079 |
| | 2 | 6466.7 | 359.294 | 6465.8 | 359.170 | 0.9 | .124 |
| | 3 | 6003.8 | 116.996 | 6000.0 | 116.857 | 3.8 | .139 |
| RMS Error | | | | | | 4.3 | .071 |

one exception, all the radial errors are positive. Also, the one negative radial error matches the one negative vertical error in Table 22. Therefore, the radial error is correlated with vertical error.

The $\theta$ errors (bearing errors) for the last flight on the B-70 range are all positive and larger than the others. The average bearing error for that survey is 0.114 degree, or 2.0 milliradian. For scoring purposes, however, an average bearing error is immaterial because it only rotates the whole array and changes the orientation of the BSS with respect to east and north by the amount of the rotation.[11] Since the BSS solution for ground track is rotated by the same amount, the BSS calculation of downrange and crossrange impact is unchanged. The east and north coordinates of impact, however, are in error by the amount of the rotation.

If, from the data of Table 22, the average azimuth errors are removed, then for downrange and crossrange scoring, as opposed to east and north scoring, the equivalent RMS survey errors are 3.5, 3.5, and 8.8 feet for east, north, and up, respectively.

11. The BSS computer program allows for the possibility of mismatch in azimuth between the BSS INS and the ground array, due presumably to INS drift. The externally surveyed array is assumed correct and a correction to INS azimuth is computed. If in fact the array coordinates are rotated by a small amount, the BSS assumes the INS is in error and corrects all INS readings appropriately.

Chapter III

# OPERATIONAL SUITABILITY

This chapter reports on the operational suitability demonstrated by the Bomb Scoring System (BSS) throughout the 3 months of handling, operation, and maintenance required for demonstration testing. In designing the tests, it was apparent that the range of experience available would be too limited for a complete or definitive evaluation of all suitability factors. However, it was felt that a first look at BSS operational suitability would still be of value even from the limited data base of this test.

Aspects of operational suitability that were observed include:

- Preflight availability
- Inflight reliability
- System maintainability
- Hardware and data utility

Each of these aspects is defined and discussed in following sections. In addition, this chapter addresses potential future applications for the BSS, as requested separately by the Deputy Director Test and Evaluation, ODDR&E.

## A. GENERAL CONSIDERATIONS

It should be borne in mind that the three systems tested were prototypes, unique and rather complex, and not designed for general field use by semiskilled operational Service personnel. The contract called for operation and maintenance by the contractor. In addition, the testing cannot truly be considered a "demonstration" in the sense of a finished product delivered by the contractor and evaluated as is. Because of some design discrepancies and the urgency expressed in producing the system, the contractor was permitted to continue to refine both hardware and software, normally completed in a developmental phase prior to demonstration. These unexpected changes, along with a tight schedule, limited comprehensive record-keeping and resulted in some personnel and procedural errors.

## B. PREFLIGHT AVAILABILITY

BSS availability in demonstration testing is defined as the ratio of the number of times one or more complete systems were ready for flight to the number of flights scheduled. This definition of availability is slightly different from the usual definition because the resources of two to three pods and six transponders could be drawn on to produce the one pod and four transponders that were normally required for each flight. The planned OT&E phase will require that all three pods and all six transponders be regularly available.

A log of operations from 15 April through 9 July 1974 appears in Appendix C. Table 24 is derived from that log and summarizes the results of operations in terms of sorties scheduled, flown, cancelled, or aborted. The results of all sorties flown are tabulated in terms of success, partial success, or failures. In each case where success was limited, responsibility is assigned. Data from Table 24 show that 5 of 96 scheduled pod sorties were cancelled for BSS nonavailability, yielding a preflight availability of

$$\frac{96 - 5}{96} = 95 \text{ percent.}$$

The table indicates that three times as many sorties were lost because of aircraft or personnel problems as were cancelled by pod nonavailability. The data may be somewhat misleading, however, in that in daily and week-to-week planning, a sortie may not have been scheduled if it appeared likely ahead of time that an operable system would not be available.

Reference 16 is a detailed analysis of scoring results prepared by the contractor, with an extrapolation of the demonstration test experience to OT&E requirements. This analysis disagrees in some specifics with the observations of this study team—notably single pod availability—because of differences in assumptions, definitions, and interpretations.[1] However, by taking into account those discrepancies

*Table 24. Operations Summary*

| | |
|---|---|
| Pod Sorties Scheduled | 96* |
| Scheduled Sorties for Which One or More Pods Were Available | 91* |
| Pod Sorties Attempted | 76* |
| Sorties Scheduled but Not Flown | |
| Because of BSS Malfunction | 5 |
| Because of Aircraft/Crew Not Ready | 7 |
| Because of Weather | 5 |
| Because of Personnel/Procedural Errors | 3 |
| | 20 |
| Sorties Attempted but Aborted in Flight | |
| Because of BSS Malfunction | 4 |
| Because of Aircraft Malfunction | 1 |
| Because of Weather | 1 |
| Because of Personnel/Procedural Errors | 1 |
| | 7 |
| Successful Pod Sorties | 49* |
| Partially Successful Sorties | |
| Success Limited by BSS | 8 |
| Success Limited by Aircraft/Crew | 5 |
| Success Limited by Personnel/Procedural Errors | 2 |
| | 15 |
| Unsuccessful Sorties | |
| Because of BSS Malfunction | 3 |
| Because of Weather | 1 |
| Because of Personnel/Procedural Errors | 1 |
| | 5 |

*Includes three sorties on which two pods were carried on a single aircraft.

1. Reference 16 addresses only bomb scoring missions, while this study includes all scheduled activities: scoring, survey, and diagnostic sorties.

affecting availability that were permanently corrected on site, the contractor's predicted OT&E availabilities appear reasonable (i.e., one pod available virtually all the time, two pods available about 90 percent of the time, and all three available about 50 percent of the time).[2]

## C. INFLIGHT RELIABILITY

Operating reliabilities of avionics systems are customarily expressed in terms of mean time between failure (MTBF), which is the total number of operating hours (usually in the thousands or hundreds of thousands) divided by the total number of failures occurring in that period of time. An MTBF derived from the limited data sample available in demonstration testing is not a realistic measure of merit for BSS reliability. The total operating hours accumulated (approximately 165) were not significantly higher than the 150-hour MTBF guaranteed by the contract, and no major hardware failure occurred during demonstration testing that can be fairly attributed to normal operations.[3] Whereas availability was defined in terms of pods considered operable when delivered to the aircraft prior to flight, reliability is defined as the ratio of the number of sorties in which the BSS functioned acceptably to the total number of sorties flown. *Acceptable* operation takes into account some inflight malfunctions that did not affect the quality of data generated. For example, a number of flights experienced a premature shutdown of the BSS because of environmental cooling problems, but late in the mission with no significant loss of scoring data. These sorties were considered successful even though the pod did not continue to function normally throughout its entire operating time.

Table 24 shows 49 completely successful pod sorties and 15 partially successful sorties in which data comparable to that required for OT&E were obtained. In addition, the BSS was apparently functioning satisfactorily on five flights that were aborted or unsuccessful for reasons other than BSS malfunction. In terms of sorties, the resulting inflight reliability of the pod is

$$\frac{49 + 15 + 5}{76} = 91 \text{ percent.}$$

The contractor analysis (Ref. 16) addresses inflight reliability (in the scoring mode only) in terms of successful sorties and of successful passes per sortie in an attempt to predict for OT&E the probability of success on any given scoring run. By subtracting the malfunctions subsequently resolved and computing the product of the probability of the pod's function-

2. This assumes that no major spare components will be available. Spares status is discussed in Section D1d. With major spares and skilled field engineers available, three-pod availability is predicted by the contractor to be better than 90 percent.

3. Procedural and software discrepancies periodically inhibited proper operation of system components, but the only hardware failures of any significance resulted from diagnostic troubleshooting in the shop.

ing with the probability of its producing valid data on a given pass, a "potential success rate" of 91.8 percent is predicted.[4]

## D. MAINTAINABILITY

Maintainability is a measure of the ease and efficiency with which the BSS can be kept in operation on a continuous routine basis. As noted previously, the BSS is highly specialized test equipment. It requires skilled field engineers; an air-conditioned maintenance laboratory, with regulated power; special tools and support equipment; spare parts, components, and subassemblies; and handling personnel.

### 1. Maintenance Support Requirements

#### a. Contractor Personnel

Litton representatives on site varied considerably both in numbers and skill level throughout the conduct of the testing, primarily because of the developmental corrections that the testing continued to require. For continuous three-pod operations, it was clearly demonstrated that at least six skilled technicians would be required in the field on a nearly permanent basis. At least one highly competent supervisor is required to provide continuity and broad expertise in system hardware, software, and component interfaces. The other technicians need not necessarily be expert in all aspects of the system and its performance, but provision must be made for continuous on-site competence in:

- Operation and maintenance of the pods.
- Operation and maintenance of the data terminal.
- Operation and maintenance of the ground support equipment.
- Operation and maintenance of the transponder/battery/antenna field units.
- Test aircraft characteristics and procedures.

Improper operation of the BSS by contractor personnel accounted for at least two unsuccessful sorties and improper maintenance accounted for at least six unproductive sortie attempts. Scheduling pressure twice caused attempts to correct problems in the field that proved counterproductive; additional sorties were lost when a field fix interferred with computer logic. Experience with attempting complex repairs in the field emphasized the requirement for both sufficient quality and quantity of personnel support, since it appeared likely that pressure from the pace of operations contributed to personnel error.[5]

4. The actual success rate demonstrated was 70.5 percent. Developmental malfunctions since corrected, hence not included in the OT&E prediction, include incorrect computer logic controlling interrogator calibration, a loose wire, improper computer repair, an incorrect fix of an A-6 power switching problem, and rework of the pod's cooling system. The prediction also excludes weather, aircraft, crew, and range problems.

5. It also highlighted the need for spare line replaceable units to allow immediate substitution of major components, with repair at a manufacturer's facility properly staffed and equipped for diagnosis and correction (Section D1d).

**b. Service Personnel Support**

While the contractor is charged with operation and maintenance of the BSS, additional semiskilled assistance is required from the host activity for loading, handling, recordkeeping, and basic housekeeping. For safe and efficient pod handling, at least two, but preferably three, men are required in addition to contractor personnel. Ideally, all loading personnel should be assigned on a permanent basis; as a minimum, the handling supervisor must be thoroughly familiar with the unique handling characteristics of the pod. For staggered three-pod operations, a single crew is sufficient; simultaneous handling evolutions multiply the number of Service support personnel required.[6] In addition to pod handling personnel, at least one man is required to set out, service, and monitor each array.

c. **Shop Support**

Contractor requirements for shop support include (Ref. 16):

- Approximately 2,000 square feet.
- Controlled temperature at 60 to 80 degrees F.
- Relative humidity less than 80 percent.
- Large door for moving pods in and out.
- Three-phase 400 Hz power with 60-amp capacity.
- Single-phase 60 Hz power with 40-amp capacity.
- Over-voltage protection.
- Telephone, benches, desks, and administrative area.

Special tools and test equipment (including dry ice storage box and pulverizer) are provided by the contractor. The laboratory provided at Eglin AFB was sufficient; however, the host activity must be made aware of the complex nature of the BSS. At Eglin, the need for regulated power supplies required some emphasis and negotiation. Base security should provide not only for protection of equipments, but for handling and stowage of some classified scoring data.

**d. Spares**

The original contractual agreement provided for government furnished spare parts, cards, and subassemblies, including one complete set of the four major pod components: the computer, the inertial unit, the power supply, and the control unit. Ample spare bits and pieces were provided, including computer cards, but funding and availability restrictions forced the contractor to work without the four major component spares. This resulted in cannibalization from one pod to another in order to deal with malfunctions. As noted earlier, the lack of major component spares did not appreciably degrade single-pod availability required for demonstration, but should be expected to reduce three-pod availability

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6. The Navy provided a crew of 8 to 10 enlisted personnel TDY at Eglin AFB throughout the testing for A-6 maintenance, pod handling, ordnance loading, and housekeeping assistance. A comparable crew was provided by the Air Force for F-111 operations.

required in OT&E by almost half. A subtler influence difficult to assess is the effect on maintenance personnel and operating equipments that might result from having to trouble-shoot and repair in the field by cannibalizing working components out of otherwise fully functional pods. Major component spares would allow single-unit substitution to isolate system malfunctions without jeopardizing functional systems. All diagnosis and repair can then be performed by the manufacturer at a facility properly equipped for precise fault diagnosis, including simulation of the dynamic environment, not available to the field technicians, where the kinds of intermittent heat and vibration problems that have plagued the BSS can be reproduced and isolated. It appears likely that spares availability would also have a direct bearing on the number and skill level of contractor representatives required on site.

## 2. Planned Maintenance

Table 25 is a compilation of routine maintenance of the BSS normally required during continuous three-pod activity. About 60 to 70 manhours per week would normally

*Table 25. Planned Maintenance Requirements for the BSS*

| *Requirement* | *Interval* | *Remarks* |
|---|---|---|
| Purge Ice Chambers | 2 hours per pod per flight | May be obviated by a drainage system fix |
| Maintain Data Center | 4 hours per week | Preventive maintenance, cleaning, and diagnostic tests |
| Check Transponder Calibration | Two men; 2 hours per pod per week | Requires all pods and transponders |
| Routine System Checks | Variable, depending on pod usage | Requires MCU; static navigation runs; check IMU velocities, etc.; check any incipient problem that may show up in BIT indications |
| Check Structural Integrity | Less than 1 hour per pod per week | Often obviated by unplanned maintenance |
| Interrogator Diagnostic Check | 1 hour per interrogator per week | |
| Service Ram Air Turbine | Approximately once each 500 operating hours | |
| Charge Batteries | 2 3 hours per day | Does not require a man in attendance throughout |
| Support Equipment Preventive Maintenance | 2 hours per week | Cleaning and adjustment of two tape readers |
| Data Processing | 1 hour per flight | Additional time may be required for telephone transmission |

be required for routine system upkeep. No absolute figure can be assigned to planned maintenance, however, since many of the routine checks may be obviated by the performance of unplanned maintenance required in the course of system operation and repair, which depends on the tempo of operations and hence is not precisely predictable. Also, routine preventive-type maintenance is often postponed and occasionally forfeited when operational commitments become pressing, as was the case at Eglin. Nonetheless, planned maintenance activities for the BSS are quite conventional and well within the normal capacity of field engineers on site, time permitting. Much of the planned maintenance was performed during weekends and off hours.

### 3. Unplanned Maintenance

While troubleshooting and repair of discrepancies that occur in the BSS can be complex, it is facilitated by system design of both hardware and software. Hardware and pod construction provide for complete access (illustrated in detail in Ref. 7) and interchangeability of all components among pods. The three pods are nearly identical, as are the six transponders, two manual control units, and two data terminals. The software design provides a built-in test (BIT) capability for both the transponders and the pod. The transponder BIT is a simple go/no-go pushbutton on the control panel. A faulty transponder is returned to the shop, where a specialized test set is available to further isolate a malfunction to the defective module.

Pod BIT is available at four levels of increasing detail. First, an external strobe light is mounted on top of the pod to indicate to the crew that the pod is not functioning and should be returned to base. Second, four lighted malfunction indicators are available at the pod control panel to indicate a computer, inertial unit, or power supply malfunction or a system functional failure. Third, the technician can query the system for a more detailed indication of the malfunction.[7] Malfunction codes are available in the computer, with an octal addition scheme provided to indicate multiple failures. Reference 7 lists the octal codes with a brief description of probable cause: power, interrogation, computer, air data, tape unit, control unit, or inertial unit malfunction. And fourth, the manual control unit can be connected to the pod to run preprogrammed test tapes for a detailed diagnosis of total or partial system operation. In addition to the BIT capability of the BSS, a basic troubleshooting technique used throughout the test was the deliberate exchange of major components between pods in an attempt to isolate elusive system malfunctions. Since some system discrepancies can only be verified in the air, at least seven pod sorties were flown primarily for diagnostic system or component checkout.

7. The control panel has a BIT selector position not currently used. Each self-test is automatic. Any of the continuous software tests that may reveal a malfunction are numbered, and this malfunction code number can be displayed on the control unit readout to aid troubleshooting.

## E. BSS UTILITY

System utility is a measure of the ease with which the BSS can be used in its designed mission. It refers to the mobility and handling characteristics of the hardware, and to the useability (both immediate and ultimate) of the data generated, which is discussed in Section F.

### 1. Mobility

Physical characteristics of the BSS hardware—pods, transponders, antennas, and shop support equipments—are denoted in Section A of Chapter I and described in detail in Reference 7. For a major shift of base, packing, crating, or palletizing and careful handling of equipments are required. The pods are most easily transported on bomb stations of tactical aircraft. The move from Eglin AFB to the first OT&E site required three pallets totaling 10,400 pounds, which was conveniently accommodated by a single C-130-type aircraft. If the pods must be moved without the availability of tactical aircraft, an additional 96 cubic feet and 3,000 pounds must be provided for. A minimum of 2 weeks takedown and setup time is required; the entire evolution must be supervised by contractor technicians.

Local base mobility can be accommodated by standard government ground equipment. Since the shape of the pod shell is identical with the SUU-16/-23 gun pod, standard gun pod handling equipments can be used where available. Lacking these, any standard trailer or dolly with a 1,000-pound capacity can be modified by the provision of a padded cradle form-fitted to the pod, or pods. Several of these alternative dolly designs are illustrated in Reference 7. For demonstration testing at Eglin AFB, these were provided without apparent difficulty by the host activity. Figure 13 shows the dolly provided, modified to accommodate two pods, which served both as a cradle for shop maintenance and the trailer for delivering the pod to the aircraft.[8]

Relocation of transponders between targets requires a pickup truck or van-sized vehicle suited to the rough terrain to be expected in some remote target areas.[9] Placement of transponders and antenna ground places is easily accomplished by hand by one man, as shown in Figure 14.

### 2. Handling and Servicing

Loading and unloading evolutions throughout demonstration testing were routinely performed with standard Air Force ground support equipments. In the shop, a 1,000-pound capacity overhead hoist was provided to shift pods from one cradle to another. Transporting

---

8. The contract provides for delivery of a simple wheeled dolly with each pod. These are useful for shop handling but are not suitable for delivery of the pod to the aircraft.

9. Little difficulty was experienced in transporting transponders around the Eglin range complex; however, remote target sites might more prudently be serviced by helicopter.

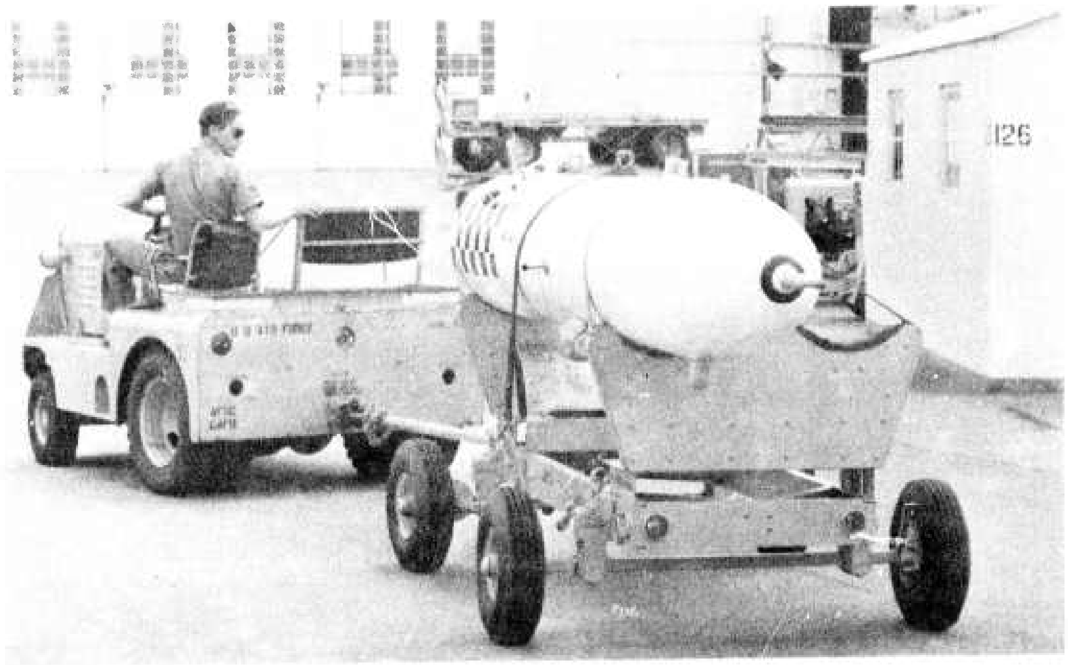


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*Figure 13. BSS Pod on a Transport Dolly*

the pod between shop and aircraft was done slowly and carefully by responsible enlisted personnel in a fashion comparable to delivering live ordnance. While the pod probe and RAT blades were potentially hazardous protrusions, the normal care routinely exercised in moving and handling the pods indicated no undue hazard to personnel. On the line, a bomb hoist was used to lift the pod from towing dolly to aircraft pylon as shown in Figure 15; it should be noted that clearance access must be provided on the towing dolly selected to allow for the bomb hoist arm. Once loaded, safety pins were inserted in the pylon release mechanism until just before takeoff.

The total pod loading and checkout procedure can normally be accomplished in 1 hour or less. The contractor requires an additional hour or more in the shop prior to the load to check the pod, load dry ice, and button up. Transport to the parked aircraft was usually accomplished in 15 to 20 minutes, uploading onto the aircraft pylon 15 to 20 minutes, and alignment and initialization in another 15 to 20 minutes. If delays occur in getting started and underway, additional time may be required to replenish the supply of cooling ice. At the completion of a pod sortie, downloading can normally be accomplished in 30 minutes or less. About 5 to 10 minutes is spent prior to aircraft shutdown to read out display data, remove the tape cartridge, and shut down the pod. After taxi to the line

LITTON SYSTEMS, INC., PHOTO LAB

*Figure 14. BSS Transponder and Antenna*

and aircraft shutdown, the download and transport back to the shop seldom requires more than 20 to 25 minutes, provided all equipment and personnel are standing by.

Servicing requirements for the pod include dry ice, ground power, alignment and initialization, and postflight readout. The requirement for servicing the BSS cooling system with dry ice was a handling detail that became unduly significant throughout demonstration testing. Procurement and stowage provided no problem. However, shaving the 50-pound $CO_2$ blocks into the pulverized form required for loading into the pod required a separate ice grinding machine, plus hand scoops, and funnels devised on site by field personnel.[10] For extended missions, or when delays occur on the line, replenishment ice can be loaded

10. Pelletized dry ice procured to correct a design deficiency in the cooling system obviated the need for pulverizing, but was no less difficult to load and handle.


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*Figure 15. BSS Loading on Aircraft Using Bomb Hoist*

into the pod at the aircraft, but the process is awkward, time consuming, and potentially dangerous. Either the pod must be downloaded, or a ladder used for access to the ice-loading ports on top of the pod (and partially blocked with the pod attached to the pylon). The evolution requires considerable familiarity, practice, and dexterity. In addition, the access panels for both dry ice loading and ground power connections are secured by fasteners requiring a special handtool.

Ground power for warmup, alignment, and initialization of the pod can be provided by standard Navy/Air Force ground power carts. During demonstration testing, this was usually the same cart used to provide starting power for the aircraft. Connecting ground power, inserting the preprogrammed tape into the pod, and attending the pod during alignment and initialization require a contractor technician at the pylon throughout the preflight evolution, as shown in Figure 16. Although this was expected to be a potential safety problem, it proved to be a simple, safe, and routine requirement. On both the A-6


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*Figure 16. Ground Support Personnel Servicing BSS*

and F-111, jet intakes and exhausts are well clear of the pylons used. Noise suppressor headsets were worn at all times by all personnel in the vicinity of the aircraft.

In the event a pod-carrying aircraft should be diverted to a base other than one where contractor field technicians are available, it is advisable (especially if data preservation is desired) to brief and equip the crew for shutdown and possible download of the pod. However, an unattended pod poses no hazard to the aircraft or personnel; it simply shuts itself off.

## F. DATA UTILITY

The validity of BSS scoring and survey results demonstrated are analyzed in detail in Chapter II. In addition to the mathematical validity provided by BSS software, the suitability of the data from an operational point of view is considered significant at two levels:

(1) Its immediate accessibility and relevance to the crew or scoring agency.
(2) Its ultimate value in assessing total performance to the weapon system tested.

A typical printout of the data immediately available to the scoring agency, termed the "release frame," is reproduced as Figure 17. Throughout the Eglin tests, a contractor technician met each returning sortie. Before engine shutdown, scores can be copied manually from the pod control unit display as a quick check to determine the validity of scoring and pod operation. The tape unit was extracted at this time (as illustrated in Figure 18) and the pod shut down. The tape unit was returned to the shop and inserted in the data terminal, which produced flat copies of the release frames within minutes, usually in time to hand to the crew as they arrived for debrief. As shown in the example in Figure 17 (and

RELEASE -- NUMBER 7

| | |
|---|---|
| COMP TIME AT RELFASE (SEC) | 6565. 954 |
| (USEC) | 321. 75 |
| DOWNRANGE MISS ERROR (FT) | 354. 9219 |
| CROSS RANGE | -521. 3438 |
| DOWNRANGE ESTIMATING ERROR (FT) | 1. 890625 |
| CROSSRANGE | 3. 34375 |
| X TARGET COORDINATE (FT) | 0 |
| Y | 0 |
| Z | 0 |
| X IMPACT COORDINATE (FT) | -6. 96875 |
| Y | -630. 6719 |
| SLANT RANGE TO IMPACT (FT) | 3627. 813 |
| BOMB TRAIL (FT) | 4671. 922 |
| TIME OF FALL (SEC) | 11. 80933 |
| ALT ERROR RANGE SENSITIVITY (FT/FT) | . 5839882 |
| VZ ERROR RANGE SENSITIVITY (FT/FT/SEC) | 3. 328125 |
| X RELEASE COORDINATE (FT) | 2728. 828 |
| Y | 1212. 953 |
| Z | 1509. 203 |
| X VELOCITY AT RELEASE (FPS) | -562. 2141 |
| Y | -373. 3523 |
| Z | -9. 390137 |
| X REL POS STD DEV (FT) | 1. 519406 |
| Y | 2. 009742 |
| Z | 2. 583375 |
| X REL VEL STD DEV (FT/SEC) | . 1229294 |
| Y | . 1746594 |
| BAROMETRIC ALTITUDE (FT) | 1953. 953 |
| TRUE AIRSPEED (KTS) | 398. 5605 |
| AIR TEMP (DEG K) | 297. 3973 |
| AIR DENSITY (SLUGS/CU FT) | 2. 178999E-3 |
| ANGLE-OF-ATTACK (DEG) | 1. 55404 |
| SIDESLIP (DEG) | . 4236629 |
| PITCH ANGLE (DEG) | . 2636504 |
| ROLL | 1. 159723 |
| HEADING | 10. 87707 |
| PITCH RATE (DEG/SEC) | . 7231665 |
| ROLL | 3. 525324 |
| HEADING | . 1258063 |
| PITCH AXIS LEVER ARM (RIGHT FT) | 20 |
| YAW (UP) | 0 |
| ROLL (FORWARD) | 0 |
| PITCH AXIS EJECTION VEL (RIGHT FT/SEC) | 0 |
| YAW (UP) | -16 |
| ROLL (FORWARD) | 0 |
| EAST WIND VELOCITY | -11. 25952 |
| NORTH | 19. 18799 |
| 0 MEAN E2 OVERLAY | 1777651612 |
| 1 | 0000777647 |
| 2 | 0002720740 |
| 3 | 1773463036 |
| 4 | 0000000000 |
| 5 | 0000000000 |
| 6 | 0000000000 |
| 7 | 0000000000 |
| 8 | 0000000000 |
| 9 | 0000000000 |
| 0 NO. OF INTERROGATIONS (CUM) | 1081 |
| 1 | 199 |
| 2 | 617 |
| 3 | 135 |
| 4 | 0 |
| 5 | 0 |
| 6 | 0 |
| 7 | 0 |
| 8 | 0 |
| 9 | 0 |

*Figure 17. Release Frame*

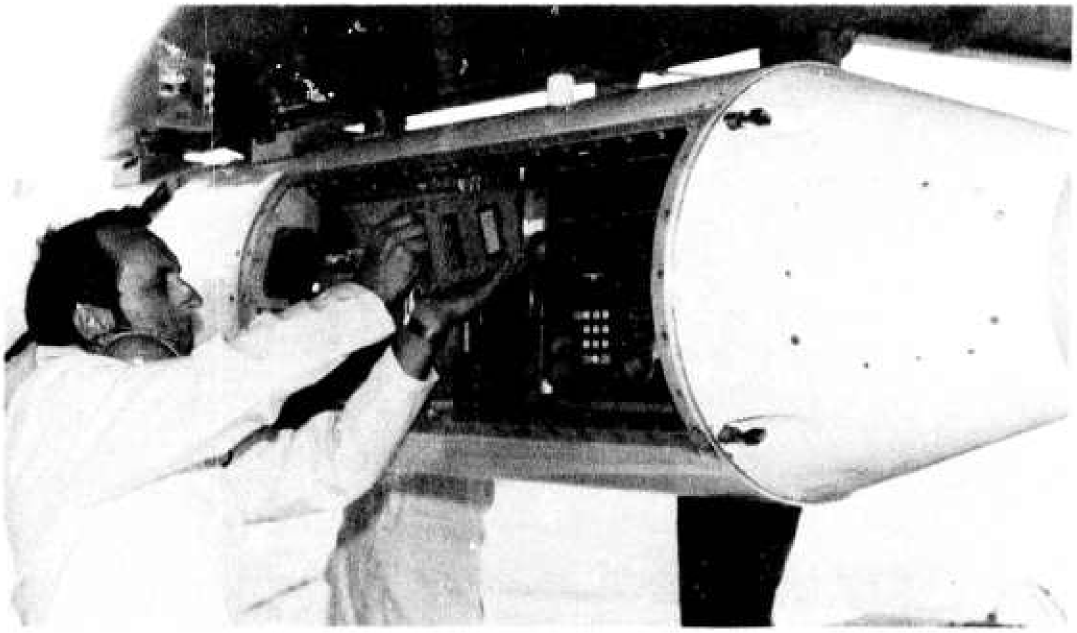

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*Figure 18. Extraction of BSS Recording Tape Unit*

described in detail in Reference 7), the crew or scoring agent can see immediately what downrange and crossrange miss distances were predicted by the BSS, with estimates of the system's own prediction errors as an indication of the validity of the prediction in each case. In addition, enough information on target, ordnance, transponder interrogations, and aircraft status is immediately available in the release frame printout to provide a quick-look estimate of the factors that might have influenced an impact prediction or scoring error.[11] The release frame format as illustrated is not necessarily fixed; software modification can provide virtually any information desired.

For more leisurely analysis, the pod records an extensive amount of data as described in Appendix A, the so-called "nine-track format." This is a comprehensive compilation of all BSS/aircraft behavior from turn-on to shutdown of the pod (Ref. 7). The entire tape can be printed out in about 30 minutes and simultaneously copied on a standard commercial nine-track tape for subsequent reference as well. Data can be displayed digitally on a cathode-ray tube if desired. Also, a single parameter, or several parameters, can be selectively extracted for examination. For example, if a poor score appears to result from an insufficient number of transponder interrogations as shown on the release frame, ranges and

11. A design feature of the BSS not demonstrated because of scheduling priorities provides a broadcast down-link to all transponders for printing out the scoring prediction. An appropriate simple data terminal is required at the transponder site, with programming to select the desired parameters to be extracted and printed out.

range rates with respect to each transponder can be extracted from the nine-track tape to determine whether the pod failed to interrogate, the transponder failed to respond, or system logic merely rejected values actually generated. Performance characteristics of the aircraft can also be determined from pod data, independent of any aircraft system. For example, altitude, airspeed, or attitude parameters recorded every 20 seconds in the navigation phase or every 1 second during the bombing run can be extracted for display and analysis. The nine-track tape also provides the contractor a comprehensive compilation of data for his continuing analysis of system performance.

As shown in Appendix A, Frame 1 of the nine-track format is basic mission data, which is inserted prior to flight and is essentially constant. Frame 2 is navigation data, normally the most voluminous, showing all parameters of pod and aircraft behavior collected every 20 seconds throughout the flight. Frame 3 is the update data recorded once each second from the time the pod commences interrogating transponders (normally at 10 miles from the target) until completion of the bomb run and post-release smoothing (normally 2 miles beyond the target, or 12 miles if no release signal is recorded). Frame 4 is the release frame previously noted, showing all parameters at the instant the release signal is received from the aircraft weapon system (and smoothed by the Kalman filter). Frame 5 is the survey data, used only when the pod is operated in the survey mode to locate relative position of the transponders from the air.[12]

## G. OPERATIONAL CHARACTERISTICS

A number of characteristics of the BSS potentially limit its operational usefulness in its present configuration. While not necessarily a disadvantage in every case, the following peculiarities of the system must be borne in mind when planning BSS operations:

(1) Only two aircraft can interrogate a single transponder array simultaneously.

(2) A single target coordinate may be designated in each array, with a maximum of three arrays or ten transponders, whichever occurs first. Use of additional targets with a given array would require manual translation of the predicted impact location expressed in east and north coordinates and available on the printout.

(3) Required geometry of the array is quite versatile, but at least one transponder should be close to the intended flightpath and another offset approximately 60 to 90 degrees from the flightpath. All transponders should be within the aircraft line-of-sight throughout the bombing run.

(4) It appears likely that aircraft maneuvers such as climbs, dives, and breakaways can actually improve BSS scoring under most circumstances. However, all maneuvers

12. The BSS self-survey mode was briefly demonstrated but never formally used to determine transponder positioning prior to scoring. Operationally, this requires a separate pod mission with prescribed maneuvers over the target array.

must clear the target area by at least 12 miles prior to commencing another run on the same array to allow the pod to reinitialize for a second scoring simulation.

(5) Virtually any type ordnance can be programmed into the BSS scoring solution. However, the single ordnance type selected for a given mission must be simulated against all targets attacked on that mission.

(6) When multiple arrays are used, the central transponders must be at least 25 miles apart.

(7) The BSS has a self-survey capability, but it requires a sortie separate from and prior to any scoring sorties.

(8) Pod cooling capacity currently limits sortie length to about 3 hours.

(9) The pod, which weighs 500 pounds, produces a significant yawing moment when carried off-center.

(10) Because of unique servicing requirements, all normal BSS operations must begin and end at a base where contractor technical support is available, currently a single base.

(11) The crew has no control over the pod for reset or restart. If a strobe illuminates, there is no option but to abort the mission.

(12) Peculiarities of the computer printout include:

(a) The assumed standard deviation for Vz, 0.316 ft/sec, is not printed out.

(b) Barometric altitude includes an intentional bias to prevent mirror solutions.

(c) Wind is expressed in feet per second vice knots.

## H. FUTURE USES FOR THE BSS

It became apparent during the demonstration testing that the capability of the scoring system to determine and report in comprehensive detail on the position and velocity of a moving platform could be profitably applied to tasks beyond bomb scoring. The Deputy Director Test and Evaluation, ODDR&E, requested that future applications of the BSS be investigated, with emphasis on potential uses of the assets procured for RABVAL. The apparent versatility and utility of the ARIS concept for other applications suggests an analytic effort well beyond the constraints of time and resources available for this study. This section is based solely on the knowledge of system characteristics and capabilities gained in initial demonstration testing.

The potential users of the system were queried for foreseeable requirements that might conceivably be fulfilled by the BSS. Reference 17 is the consolidated Air Force response and Reference 18 is the Chief of Naval Operations response for Navy and Marine Corps activities. While both felt it too early in the developmental cycle to establish firm commitments, the following potential applications were identified by the Services:

- Crew training
- Aircraft/weapon system test and evaluation
- Range instrumentation
- Aerial survey
- Scoring of major field exercises

Both Services expressed reservations, however, on the major undetermined issues of system capability, cost, and reliability.

Although limitations on time and resources precluded definitive analysis, experience gained in the demonstration tests permits reasonable speculation on potential future uses for the BSS. As is, or with increasing levels of engineering and software modification, the system could clearly be of value in bomb scoring, range instrumentation, and tactical warfare. Each of these applications is discussed below in general terms, with some specific programs suggested without any attempt at substantive justification versus programs already in being.

## 1. Bomb Scoring

Bomb scoring is the most immediate application for the BSS, essentially available without further modification. Current radar bomb scoring sites can seldom claim a scoring CEP less than 200 feet, and some claim no better than 500 feet. The BSS has already demonstrated an order-of-magnitude improvement in scoring accuracy over these sites, which is clearly of value in OT&E of ongoing radar bombing systems such as the later versions of the B-52 and the B-1. It appears that the system could be profitably utilized in OT&E of visual delivery systems as well. Its performance at Eglin suggests that the kinds of maneuvering involved in visual delivery, such as dives, climbs, breakaways, and lofts can actually enhance BSS performance by providing more variation in geometry about the transponder array than does a conventional straight and level radar delivery. Visual systems currently in procurement, such as the A-10, A-6, and A-7 TRAM, and even the secondary air-to-ground capability of the F-14 and F-15, would be amenable to operational evaluation using the BSS for scoring.[13]

On a broader scale, the BSS could be used as a scoring device for training exercises. Its versatility can provide scoring over a wide variety of realistic targets and terrains, including cultural sites such as major cities and airfields, and conceivably (with software modification) could be used against ships at sea if the appropriate baseline could be provided by task group geometry for transponders. For extensive training use or procurement of a significant number of new pods, an extensive redesign to provide a smaller, simpler device would appear prudent.

Finally, the BSS could profitably be employed as is in the on-going evaluation of unguided weapon performance, both power- and gravity-delivered. Rather than expending

13. For light aircraft, the pod might have to be carried on the center station to avoid the large off-center yawing moment observed under some circumstances on the A-6 and F-111.

large numbers of test weapons, particularly expensive or few-of-a-kind rounds, it appears feasible to calibrate a few sample deliveries with the BSS, and complete weapons performance tests using proven BSS simulations.

### 2. Range Instrumentation

The BSS as configured is well suited for many types of testing requiring precision range instrumentation. As indicated in Chapter I, its accuracy compares favorably with the cinetheodolites and the laser tracker used in the demonstration test. It also has a number of advantages over the current conventional range instrumentation systems: it is self-contained, has an all-weather capability, is highly mobile, and reports in near real time. These advantages would have to be weighed against the disadvantages of increased costs, its complexity, and the size, weight, and power requirements. While it appears feasible to shrink the size of the system by mechanical redesign, the large pod can be advantageous for instrumentation work. Even if system components were reduced in size and complexity, extra room in the pod could provide for the installation of additional instrumentation cameras, tracking lights, accelerometers, counters, and the like, that might be required in specific tests of a given system.

In addition to range instrumentation, the BSS could aptly be applied to verification testing of inertial systems and other types of precision navigation equipments. The on-going Completely Integrated Reference Inertial System program is developing hardware and procedures to test inertial systems in a dynamic environment. The BSS may be able to provide that kind of comparative instrumentation as is, provided a common environment with the system being tested could be provided. In this regard, it might well be applied to the verification testing of guidance components of inertially controlled missiles.

As an adjunct to its position fixing capability, the survey mode available in the BSS provides a capability for position fixing on the ground. Since the relative positions of up to six transponders can be quickly established to an accuracy of 6 to 9 feet[14] by the pod (Table 22, Chapter II), the system might well be adaptable to test range programs in which instrumentation arrays must be varied frequently, perhaps on short notice. Any six positions on the ground at or near which a transponder could be placed can be surveyed with respect to each other and any desired ground reference with a 15- to 20-minute flyover.

### 3. Tactical Uses

Any extensive tactical employment of the BSS presupposes the procurement of a large number of pods with redesign to modify the somewhat impractical size, weight, cooling, and power supply characteristics of the current prototype. Given an operationally suitable BSS unit, a number of feasible tactical applications are apparent. Basically, the pod concept permits the temporary addition of an all-weather precision bombing and navigation

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14. Software refinements could probably improve survey accuracy to about 3 feet.

system to an otherwise cheap and simple aircraft. Unit costs can be minimized in the production of lightweight fighters and attack bombers, remotely piloted vehicles, and even helicopters. A complex bomb/nav system need not be designed into the aircraft, but only added when needed (and interchangeable among other aircraft) for a specific mission, retaining the basic lightweight capability for the majority of tactical applications. Another approach could even provide for a tie-in with some equipments already installed in the aircraft, such as a computer or inertial platform.

Given a temporary capability for precision all-weather bombing and navigation by the attachment of a pod, any number of otherwise unsophisticated aircraft might be employed in such roles as close air support, interdiction, or reconnaissance. The basic concept of position fixing by transponder for delivery of ordnance in close support of ground troops has already been demonstrated by a parent version of the BSS developed for the Close Air Support System (CLASS) program, with delivery accuracy reported to be excellent (Ref. 5). A redesign of the CLASS software using improvements from the BSS design would give a capability somewhere between the CLASS results and the accuracy demonstrated with the BSS. This could be accomplished rather simply and would give an acceptable capability for close air support.

CLASS uses one transponder co-located with a ground observer. After the ground observer determines the location of the transponder relative to a desired target, this information is transmitted to the pod computer via transponder data link. The aircraft flies an appropriate curvilinear path relative to the transponder to determine aircraft position and velocity. With this information, and target location, the pod computer generates steering signals to a bomb release point.

Another optional use of the same basic system would employ two or more transponders at known locations (relative to the target) in friendly territory. In a manner similar to a bomb scoring run, aircraft position and velocity would be determined accurately by flying over the transponder array. This information could be used to direct the aircraft on a bombing or reconnaissance mission. With an accurate inertial system in the pod and with a very accurate update of both position and velocity from flying over the array, it should be possible to penetrate a considerable distance into enemy territory before bombing accuracy degrades, even beyond line-of-sight from the array.

In reconnaissance work the value of a system comparable to the BSS would lie in its ability to report with precision the exact location of the photographic vehicle, manned or unmanned, at the instant each picture was taken, and possibly in a common grid with that used for the bombing activity.

A second major tactical application of the BSS concept exists in its possible adaptation as an all-weather airborne locator system, providing, in effect, a known grid defined by fixed or mobile transponders within which the locations of individual units of a task force at sea, a tank battalion operating over an extended battlefield area, or any combination of mobile units could be continuously tracked and reported. It would require an extension of the current survey mode of the BSS, incorporating its downlink capability to a central command and control post. It is not inconceivable that the command post itself could be installed in a tank, truck, or mobile vehicle.

The precision position-fixing capability of the BSS could also be modified to provide a continuous all-weather cockpit readout of aircraft position with respect to appropriately placed transponders on a friendly airfield for use as an all-weather landing system. While the accuracy and reliability of the BSS is hardly comparable to current fixed installations for all-weather landing, it could provide an acceptable forward area capability quickly for all-weather flight operations prior to the installation of a more permanent fixed system.

For all the applications indicated, the mechanization is already inherent in the BSS, requiring only software modifications, albeit in some applications extremely challenging ones. It appears likely that all the applications suggested herein for BSS extensions are currently available in other systems or combinations of systems. To determine the relative costs and effectiveness of the BSS vis-a-vis other equipments would require a major analytical investigation.

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# APPENDIX A

## INFORMATION AVAILABLE FROM 9-TRACK DATA TAPE RECORD

# Appendix A

## INFORMATION AVAILABLE FROM 9-TRACK DATA TAPE RECORD

*Frame 1, Mission Data (recorded once)*

- Date code
- Flight number
- Greenwich Mean Time
- Computer time at GMT
- Bomb type
- Aircraft type/tail number
- Pilot number
- Weapon operator number
- Computer tape serial number
- Various ballistics parameters (16)
- Transponder 1 (central transponder) identification number
- Transponder 1 (central transponder) longitude
- Transponder 1 (central transponder) lattitude
- Transponder 1 (central transponder) altitude
- Transponder 1 (central transponder) biases (4)
- Transponder 2 east displacement
- Transponder 2 north displacement
- Transponder 2 up displacement
- Transponder 2 biases (4)
- (similarly for remaining 10 possible transponders)

*Frame 2, Navigation Data (recorded every 20 seconds)*

- Computer time
- Hardware status (5)
- Groundspeed
- Groundtrack heading
- Heading
- Vertical velocity
- Wind velocity, east
- Wind velocity, north
- True airspeed
- Angle-of-attack
- Sideslip angle
- Mach number
- Static temperature
- Latitude
- Longitude
- Inertial altitude
- Barometric altitude
- Altitude loop error function

*Frame 3, Update Data (recorded every second while in vicinity of array, within approximately 10 miles from center transponder)*

Computer time
Computed minus measured range (range error)
Computed minus measured delta range (delta range error)
Failure indication if either range error or delta range error exceeds 2 $\sigma$
Transponder identification code
Covariance of X position
Covariance of Y position
Covariance of Z position
Covariance of X velocity
Covariance of Y velocity
Roll angle
Covariance of X tilt
Covariance of Y tilt
Covariance of azimuth
Measured range
Measured delta range
Heading
Bias covariance X position*
Bias covariance Y position*
Bias covariance Z position*
Bias covariance X velocity or 0*
Bias covariance Y velocity or 0*
Computed bias X position†
Computed bias Y position†
Computed bias Z position†
Computed bias X velocity or 0†
Computed bias Y velocity or 0†
Pitch
X position, uncorrected (from INS)
Y position, uncorrected (from INS)
Z position, uncorrected (from INS)
X velocity, uncorrected (from INS)
Y velocity, uncorrected (from INS)
Z velocity (from INS)
X position correction (from Kalman filter)
Y position correction (from Kalman filter)
Z position correction (from Kalman filter)
X velocity correction (from Kalman filter)
Y velocity correction (from Kalman filter)
X tilt correction (from Kalman filter)
Y tilt correction (from Kalman filter)
Z tilt correction (from Kalman filter)

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*X, Y, Z, VX, VY release point correction covariances in scoring mode, or X, Y, Z transponder position correction covariances in survey mode.

†X, Y, Z, VX, VY release point correction in scoring mode, or X, Y, Z transponder position correction in survey mode.

*Frame 4, Release Data (recorded for each release)*

Compter time
Downrange miss error
Crossrange miss error
Downrange estimating error
Crossrange estimating error
X target coordinate
Y target coordinate
Z target coordinate
X impact coordinate
Y impact coordinate
Slant range to impact
Bomb trial
Time of fall
Altitude error range sensitivity
Vertical velocity error range sensitivity
X release coordinate
Y release coordinate
Z release coordinate
X velocity at release
Y velocity at release
Z velocity at release
X release position variance
Y release position variance
Z release position variance
X release velocity variance
Y release velocity variance
Barometric altitude
True airspeed
Air temperature
Angle-of-attack
Sideslip angle
Pitch
Roll
Azimuth
Pitch rate
Roll rate
Azimuth rate
Pitch lever arm (from pod to bomb station)
Yaw lever arm (from pod to bomb station)
Roll lever arm (from pod to bomb station)
Pitch ejection velocity
Yaw ejection velocity
Roll ejection velocity
East wind velocity
North wind velocity
Transponder quality (10)
Cumulative number of interrogations for each transponder (10)

*Frame 5, Survey Data (recorded for each survey)*

Central transponder identification number
Central transponder longitude
Central transponder latitude
Central transponder altitude
Outlying transponder 1 identification number
Outlying transponder 1 east displacement
Outlying transponder 1 north displacement
Outlying transponder 1 up displacement
(similarly for remaining 5 possible outlying transponders)
Various data pertaining to transponder performance (15)
X variance for outlying transponder 1
X, Y covariance for outlying transponder 1
X, Z covariance for outlying transponder 1
Y variance for outlying transponder 1
Y, Z covariance for outlying transponder 1
Z variance for outlying transponder 1
(similarly for remaining 5 possible outlying transponders)

# APPENDIX B

## PROCEDURE FOR USING BSS AND BALLISTIC DISPERSION INFORMATION TO DETERMINE THE CEP OF AN AIRCRAFT BOMBING SYSTEM

## Appendix B

## PROCEDURE FOR USING BSS AND BALLISTIC DISPERSION INFORMATION TO DETERMINE THE CEP OF AN AIRCRAFT BOMBING SYSTEM

### A. CEP OF AIRCRAFT BOMBING SYSTEM

The CEP of an aircraft bombing system, including effects of aircraft, crew, and bombs, may be determined from the expression

$$CEP_{system} \cong \sqrt{CEP_{raw}^2 - CEP_{BSS}^2 + CEP_{BD}^2} ,$$

where

$CEP_{raw}$ is CEP determined from BSS scores. (This CEP is uncorrected for BSS error and ballistic dispersion of bombs.)

$CEP_{BSS}$ is CEP of the Bomb Scoring System for the delivery profiles flown and type of bomb used.

$CEP_{BD}$ is CEP of ballistic dispersion for bombs assumed dropped.

To obtain $CEP_{raw}$, several simulated drops should be made with the bombing system. The miss distance for each drop can be obtained from the BSS data printout by

$$\text{Miss Distance} = \sqrt{(\text{downrange miss})^2 + (\text{crossrange miss})^2}$$

After rank ordering the miss distances, the median miss can be found. The $CEP_{raw}$ is just this median miss distance.

The $CEP_{BSS}$ can be obtained by two different methods. For the first, the $CEP_{BSS}$ of each drop is found by [1]

$$CEP_{BSS} \text{ (for each drop)} \cong 0.59 \text{ (downrange + crossrange estimating errors).}$$

1. The formula $CEP \cong 0.5887\ (\sigma_x + \sigma_y)$ is an approximation used for finding the CEP of an elliptical normal distribution given the standard deviation, $\sigma_x$ and $\sigma_y$, along the two axes of the distribution. The downrange and crossrange estimating errors included on the BSS printout can be assumed to be the standard deviations along those axes of an elliptical normal distribution of scoring errors.

The individual CEPs are then averaged to obtain $CEP_{BSS}$. For the second method, an appropriate RMS radial scoring error is determined from Table 17 by comparing the profile in use with those of the table. This RMS radial error is then converted to $CEP_{BSS}$ by the approximation

$$CEP_{BSS} \cong 0.78 \times \text{RMS radial scoring error.}$$

The $CEP_{BD}$ can either be some nominal value or, for Mk 84 and Mk 82R bombs, the scoring CEPs presented in Section B of Chapter II can be taken as an approximation of ballistic dispersion. Those values from Section B are 1.5 to 2.4 mils for Mk 84 depending on adjustment used, and 12 to 16 mils for Mk 82R.

## B. CONFIDENCE INTERVALS FOR $CEP_{system}$

There is some uncertainty in $CEP_{raw}$ because only a finite sample of bomb drops is used. If

$$CEP_{raw} \geqslant 2 \times CEP_{BSS},$$

and

$$CEP_{raw} \geqslant 2 \times CEP_{BD},$$

which is the usual case, then this uncertainty shows up relatively undiminished in $CEP_{system}$ as well. The amount of the uncertainty depends on the shape of the distribution (e.g., whether it is elliptical normal,[2] what the ratio of axes for the ellipse are, whether it has biases).

Figure B-1 shows 90 percent confidence intervals for an elliptical normal distribution with a 3 to 1 ratio of axes. From a set of confidence interval curves such as Figure B-1, the 90 percent confidence interval can be obtained by entering the curve with N, the number of drops, reading off the upper and lower curve values, and multiplying these values by $CEP_{system}$. Then, 90 percent of the time the true $CEP_{system}$ will lie between the two values so obtained.

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2. Elliptical normal means a distribution

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right),$$

where x and y are oriented along the axes of the ellipse, and $\sigma_x$ and $\sigma_y$ are standard deviations for those axes.

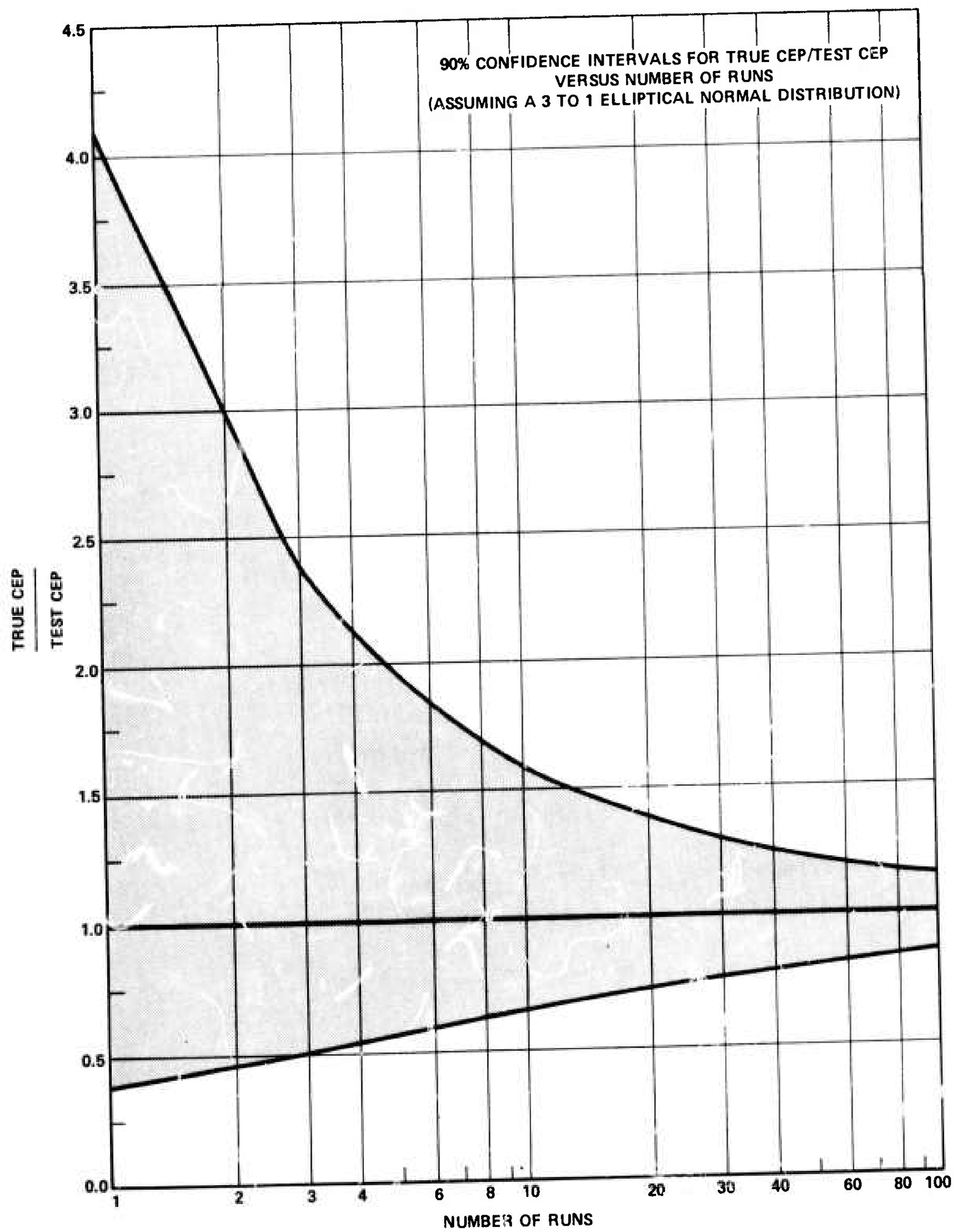


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*Figure B-1. Confidence Intervals for True CEP*

## C. HYPOTHETICAL EXAMPLE FOR CALCULATING $CEP_{system}$ AND CONFIDENCE INTERVALS

As a hypothetical example, assume that 12 drops were made and that $CEP_{raw}$, $CEP_{BSS}$, and $CEP_{BD}$ were–

$CEP_{raw}$ = 353 feet median miss from the 12 BSS printouts

$CEP_{BSS}$ = 19 feet average $CEP_{BSS}$ from the 12 BSS printouts

$CEP_{BD}$ = 37 feet from a nominal dispersion assumption

then

$$CEP_{system} = \sqrt{353^2 - 19^2 + 37^2} = 354.4 \text{ feet.}$$

Note that $CEP_{system}$ is greater than two times both $CEP_{BSS}$ and $CEP_{BD}$.

From a cursory examination of the 12 miss distances, there is no evidence to preclude assuming the distribution normal. Since it can also be assumed that the ratio of standard deviations for the axes is about 2.6 to 1, the curve for 3 to 1 ellipses is chosen (Figure B-1). Entering the curve with 12 runs gives

$$0.65 \leqslant \frac{\text{True CEP}}{\text{Test CEP}} \leqslant 1.55 \quad .$$

Therefore, the best estimate of $CEP_{system}$ is

$$CEP_{system} = 354 \text{ feet} \quad ,$$

and, with 90 percent confidence, the true $CEP_{system}$ is within the interval

$$0.65 \times 354 = 230 \text{ feet} < CEP_{system} < 1.55 \times 354 = 549 \text{ feet.}$$

# APPENDIX C

# DEMONSTRATION TEST OPERATIONS LOG

# Appendix C

*Demonstration Test Operations Log*

| Date | Aircraft | Pod | Sortie Operating Time (min) | Cumulative Operating Time (hr:min) | Sortie Results | Remarks |
|---|---|---|---|---|---|---|
| 4-15 | F-111 | 2 | | | Cancelled | Weather |
| 4-16 | F-111 | 2 | 131 | | Success | Computer unit malfunction; data OK |
| 4-17 | F-111 | 2 | 165 | | Success | |
| 4-18 | F-111 | 2 | 169 | | Partial Success | Weapon system malfunction |
| 4-19 | F-111 | 2 | 125 | | Success | Verify scoring mode software |
| 4-19 | F-111 | 2 | 118 | | Success | Survey mode checkout |
| 4-22 | A-6 | 2 | 146 | 14:14 | Success | |
| 4-22 | F-111 | 2 | | | Cancelled | BSS malfunction |
| 4-23 | | | | | Cancelled | BSS malfunction |
| 4-24 | | | | | Cancelled | BSS malfunction |
| 4-25 | A-6 | 1 | 206 | | Success | |
| 4-25 | F-111 | 1 | 153 | 20:13 | Success | |
| 4-26 | A-6 | 2 | 184 | | Unsuccessful | Transponders misplaced |
| 4-27 | A-6 | 2 | | | Air Abort | Strobe; aircraft power shutoff |
| 4-27 | A-6 | 2 | 166 | | Success | Environmental shutdown on way in |
| 4-29 | A-6 | 2 | | | Air Abort | Incorrect inputs |
| 4-29 | F-111 | | | | Ground Abort | Unsafe tire |
| 4-30 | A-6 | 1 | | | Ground Abort | Hydraulic leak |
| 4-30 | F-111 | 2 | | | Air Abort | Strobe; pod malfunction |
| 5-1 | A-6 | 1 | 178 | | Partial Success | Environmental reset destroyed some data |
| 5-1 | F-111 | 1 | | | Cancelled | Survey BSS malfunction |
| 5-1 | F-111 | 1 | | | Cancelled | Survey BSS malfunction |
| 5-6 | A-6 | 2 | 170 | | Partial Success | Survey no interrogation after 1st pass |
| 5-7 | F-111 | 2 | | | Cancelled | No range support |
| 5-7 | F-111 | 1 | 110 | | Success | |
| 5-8 | A-6 | 1 | | | Air Abort | Strobe; pod malfunction |
| 5-9 | A-6 | 1 | 50 | | Partial Success | Survey data unsatisfactory |
| 5-9 | F-111 | 1 | | | Air Abort | Interrogator lock-up |
| 5-13 | F-111 | 2 | 167 | | Success | |
| 5-13 | A-6 | 2 | 109 | 39:07 | Partial Success | Hung ordnance |
| 5-14 | F-111 | 1 | 177 | | Unsuccessful | No bomb release signal |
| 5-14 | A-6 | 1 | 142 | | Partial Success | Hung ordnance |
| 5-15 | F-111 | 2 | 162 | | Success | |
| 5-15 | F-111 | 1 & 2 | 157 (x 2) | | Success | Software check on 2nd pod survey |
| 5-16 | A-6 | 2 | 85 | 53:47 | Success | Survey |
| 5-20 | F-111 | 2 | 153 | | Success | |
| 5-20 | A-6 | 2 | 167 | | Success | |
| 5-21 | A-6 | 1 | 206 | | Success | Environmental circuit breaker popped |
| 5-21 | F-111 | 1 | 196 | | Success | Environmental malfunction after landing |
| 5-22 | A-6 | 2 | 232 | | Success | Environmental malfunction after landing |
| 5-22 | F-111 | 2 | 143 | | Partial Success | Weather cancelled after 5 runs |
| 5-23 | A-6 | 2 | 134 | 74:18 | Success | Survey |
| 5-28 | F-111 | 1 | 153 | | Success | |
| 5-28 | A-6 | 1 | 134 | | Success | |
| 5-29 | F-111 | 1 | 155 | | Success | Environmental malfunction after landing |
| 5-29 | A-6 | 1 | 176 | | Success | Environmental malfunction after landing |

| Date | Aircraft | Pod | Sortie Operating Time (min) | Cumulative Operating Time (hr:min) | Sortie Results | Remarks |
|---|---|---|---|---|---|---|
| 5-30 | A-6 | 1 | 152 | | Success | 3 runs cancelled by weather |
| 5-31 | F-111F (Mt.H) | 2 & 3 | 90 (x 2) | 85:28 | Success | Environmental/RAT diagnostic flight |
| 6-1 | F-111 | 3 | 60 | | Success | RAT diagnostic flight |
| 6-3 | F-111 | 2 | 123 | | Success | |
| 6-3 | F-111 | 2 | 129 | | Success | Environmental malfunction upon leaving range |
| 6-4 | A-6 | 2 | 30 | | Air Abort | Weather |
| 6-4 | F-111 | 2 | | | Cancelled | Weather |
| 6-5 | A-6 | 2 | 152 | | Success | |
| 6-5 | F-111 | 2 | 152 | | Success | |
| 6-6 | | | | | Cancelled | Weather |
| 6-7 | A-6 | 2 | 144 | | Success | Central transponder malfunction |
| 6-10 | | | | | Cancelled | Weather |
| 6-10 | | | | | Cancelled | Weather |
| 6-11 | F-111 | 3 | 215 | | Success | Operating on RAT |
| 6-11 | A-6 | 2 | 133 | | Partial Success | CIU* data only; recorder malfunction |
| 6-12 | F-111 | 3 | 160 | | Success | |
| 6-12 | A-6 | 2 | 173 | 111:37 | Success | |
| 6-14 | F-111 | 3 | | | Cancelled | Unexploded ordnance on range |
| 6-17 | A-6 | 2 | 229 | | Partial Success | No interrogation; bad cable |
| 6-17 | F-111 | | | | Cancelled | Aircraft NOR† for generator |
| 6-18 | A-6 | 2 | 170 | | Success | 3 ballistic camera runs |
| 6-18 | A-6 | 1 | 191 | | Success | |
| 6-19 | A-6 | 2 | 180 | | Success | 3 ballistic camera runs |
| 6-19 | F-111 | 1 | 148 | | Success | |
| 6-20 | F-111 | | | | Cancelled | Survey aircraft NOR for ADC |
| 6-20 | A-6 | 2 | 177 | 129:52 | Unsuccessful | Survey interrogator locked in calibration |
| 6-24 | F-111 | | | | Cancelled | Crew NOR for rest |
| 6-24 | A-6 | 1 | 158 | | Partial Success | Environmental reset destroyed some data |
| 6-25 | F-111 | 2 | 30 | | Air Abort | Landing gear emergency |
| 6-25 | A-6 | 1 | 157 | | Success | |
| 6-26 | A-6 | 2 | 103 | | Partial Success | Delayed by aircraft power problem |
| 6-26 | F-111 | | | | Cancelled | No time or range support |
| 6-27 | A-6 | 2 | 105 | | Success | |
| 6-27 | F-111 | 1 & 3 | 102 (x 2) | | Success | Engine failure |
| 6-28 | F-111 | 2 | 150 | 144:59 | Success | Ballistic camera runs |
| 7-1 | A-6 | 2 | 98 | | Success | |
| 7-1 | F-111 | | | | Cancelled | Aircraft NOR; survey |
| 7-2 | F-111 | | 71 | | Unsuccessful | No data; interrogator malfunction |
| 7-2 | A-6 | | | | Cancelled | Aircraft NOR |
| 7-3 | A-6 | 1 | 88 | | Success | Survey |
| 7-5 | F-111 | 1 | 118 | | Partial Success | Power umbilical loose |
| 7-5 | A-6 | 1 | 130 | | Partial Success | Power cut off by switching |
| 7-8 | A-6 | 1 | 138 | | Unsuccessful | No data; PCU** wiring error |
| 7-8 | F-111 | 1 | 130 | | Partial Success | Data recording lapse |
| 7-9 | F-111 | 3 | 120 | | Success | High speed RAT runs |
| 7-9 | A-6 | 3 | 139 | 165:11 | Partial Success | Weather/traffic interference |

*Control indicator unit.

†Not operationally ready.

**Power control unit.